

Assessment of Passive Design Strategies for Thermal Comfort in Residential Buildings in Ede, Osun State, Nigeria

Olayiwola Mojeed^{1*}, Steve Jayeoba¹, Adeleke Ogunkoya¹, Olanrewaju Samuel Jacob¹,

¹ Department of Architecture, Lead City University, Ibadan

Steve Jayeoba: Jayeoba.steve@lcu.edu.ng

Adeleke Ogunkoya: adelekeogunkoya@gmail.com

Olanrewaju Samuel Jacob: olanrewaju.samuel@lcu.edu.ng

Corresponding author: abdulmajeedolayemi28@gmail.com

<https://doi.org/10.56201/ijemt.vol.12.no9.2026.pg43.54>

Abstract.

The increasing prevalence of thermal discomfort in residential buildings within tropical climates has intensified the need for climate-responsive architectural solutions, particularly passive design strategies that reduce reliance on mechanical cooling systems. This study assesses the implementation of passive design strategies for improving thermal comfort in residential buildings in Ede, Osun State, Nigeria. A mixed methods approach was adopted, combining field observation, building audit checklists, and occupant-based assessments across 40 residential buildings. The study examined key passive design parameters including building orientation, natural ventilation, window-to-wall ratio, shading devices, roof insulation, courtyard integration, vegetation, ceiling height, and operable windows. Findings indicate that natural ventilation is the most commonly adopted passive strategy, whereas roof insulation and courtyard-based designs are the least implemented. Specifically, natural ventilation is fully present in 55.0% of the audited buildings, while 55.0% completely lack roof insulation and 62.5% do not incorporate courtyards. Overall, the buildings exhibit a moderate to low level of integration of passive design principles, relying mainly on basic ventilation rather than a comprehensive climate-responsive system. The study concludes that residential buildings in Ede require improved integration of holistic climate-responsive strategies. It recommends stronger policy enforcement, architectural design innovation, and increased awareness to promote sustainable residential development in tropical regions.

Keywords: *Passive design, thermal comfort, residential buildings, natural ventilation, climate-responsive architecture.*

1.0 Introduction

The rapid increase in urbanization, population growth, and climate change has intensified concerns regarding indoor thermal conditions in residential buildings, particularly in developing countries located within tropical climatic regions. Residential buildings account for a significant proportion of global energy consumption, largely due to the increasing dependence on mechanical cooling systems to maintain comfortable indoor environments. In many parts of Nigeria, rising ambient temperatures and poor building design practices have contributed to thermal discomfort among occupants, resulting in increased energy use, reduced productivity, and adverse health

implications. Consequently, there is growing interest in the adoption of passive design strategies as sustainable alternatives for achieving thermal comfort while minimizing energy demand.

Passive design strategies refer to architectural and environmental design approaches that utilize natural climatic resources to regulate indoor conditions without relying heavily on mechanical systems. Such strategies include proper building orientation, natural ventilation, shading devices, building envelope optimization, landscaping, thermal insulation, and the use of climate-responsive materials. Studies conducted in different climatic regions have demonstrated the effectiveness of these strategies in improving indoor thermal conditions and reducing energy consumption.

In Nigeria, several studies have highlighted the relationship between building design and thermal comfort. Madukwe et al. (2019) investigated thermal comfort conditions in traditional residential buildings and observed that occupants generally experienced conditions ranging from cool to slightly warm. The study further revealed that inadequate ventilation contributed significantly to thermal discomfort, emphasizing the importance of improved airflow through design interventions such as high-level window placement. Although the research demonstrated the significance of passive ventilation measures, its focus was limited to traditional housing forms and did not address contemporary urban residential buildings.

Similarly, Ochedi and Taki (2019) developed a framework for energy-efficient residential building design in Nigeria and identified considerable opportunities for reducing energy demand through bioclimatic design principles. Their findings emphasized the importance of stakeholder collaboration and climate-responsive design in improving building performance and occupant wellbeing. However, the study concentrated primarily on developing a general framework for energy efficiency and did not provide a detailed evaluation of individual passive design strategies and their effectiveness in enhancing thermal comfort.

Research conducted in other building sectors has also provided useful insights into passive design performance. Bello et al. (2025), in their assessment of higher education buildings in Bauchi, reported inadequate implementation of passive design measures such as shading, orientation, and natural ventilation. The study demonstrated that improved shading systems and reflective building surfaces could substantially enhance indoor comfort conditions. Likewise, Oluwatayo and Nduka (2024) found that passive cooling features, including operable windows and courtyard designs, significantly influenced thermal comfort levels in office buildings located in Abuja. These findings indicate that passive design strategies can effectively improve indoor environmental quality across different building types. Evidence from international studies further supports the effectiveness of passive design approaches. Through a comprehensive review of residential buildings located in hot climatic regions, Hu (2024) reported that passive design strategies can lower indoor temperatures, reduce cooling loads, improve thermal comfort periods, and achieve substantial energy savings. Similarly, Afolabi and Adedire (2023) identified a wide range of adaptive responses to overheating in urban residential environments, including urban planning measures, building design modifications, insulation improvements, and occupant behavioural adjustments. Their review emphasized the need for greater implementation and performance evaluation of these strategies in real-world settings. Natural ventilation remains one of the most widely studied passive cooling techniques in tropical climates. Studies conducted in residential buildings in Abuja by Adedayo and Lawal (2023) revealed that natural ventilation significantly improves thermal comfort while reducing dependence on mechanical cooling systems. Nevertheless, the studies reported that ventilation principles are often inadequately integrated into residential building design, particularly in multi-storey developments. Supporting these findings, Wang and Wong

(2007) demonstrated that natural ventilation can provide acceptable indoor comfort conditions for substantial periods in hot-humid climates when supported by appropriate façade design and adequate wind access.

The effectiveness of cross ventilation has also been confirmed through experimental studies. Palomo et al. (2025) validated the potential of cross ventilation as a natural cooling strategy and reported notable reductions in indoor temperature alongside significant improvements in occupant comfort. These findings reinforce the importance of ventilation-oriented design in reducing thermal stress in buildings situated within warm climatic regions.

Beyond ventilation, emerging passive design approaches involving green infrastructure have shown promising results. Joshua and Ayinla (2025) examined residential buildings incorporating vertical greenery systems in Lagos and found that vegetation-based design solutions contributed to reduce heat stress and improved thermal comfort. Similarly, Zamwawosayi et al. (2025) reported that passive measures such as proper orientation and cross ventilation reduced indoor temperatures considerably in residential buildings across different socioeconomic districts of Abuja. Despite these benefits, the researchers noted generally poor implementation of climate-responsive design strategies, particularly in low- and middle-income residential developments.

The relationship between spatial configuration and thermal comfort has also attracted increasing attention. Chen et al. (2025) demonstrated that factors such as orientation, openness, wind accessibility, and spatial morphology significantly influence thermal conditions and environmental satisfaction in residential settings. Their findings suggest that architectural form and spatial organization play important roles in determining indoor comfort performance and should be considered in climate-responsive housing design.

Furthermore, Abdullahi et al. (2025) highlighted the effectiveness of building envelope optimization strategies, including insulation, advanced glazing systems, and green roofs, in reducing heat gain and enhancing thermal comfort. Although their research focused on institutional buildings, the findings provide valuable insights into the application of passive cooling principles in the broader built environment.

Despite the growing body of literature on thermal comfort and passive design strategies, several gaps remain evident. Many existing Nigerian studies have focused on traditional housing, institutional buildings, office environments, or specific passive design elements rather than providing a comprehensive assessment of passive design strategies in urban residential buildings. Additionally, limited empirical evidence exists regarding how residents perceive the effectiveness of passive design measures in medium-sized urban centres such as Ede, Osun State. Variations in climatic conditions, housing typologies, socioeconomic characteristics, and urban development patterns further necessitate localized investigations to understand the suitability and effectiveness of passive design interventions.

Therefore, this study assesses passive design strategies for thermal comfort in residential buildings in Ede, Osun State, Nigeria. The study seeks to evaluate the extent to which passive design measures are incorporated into residential buildings, examine occupants' perceptions of thermal comfort, and identify the most effective strategies for improving indoor environmental quality. The findings are expected to contribute to climate-responsive residential design practices and support the development of sustainable housing solutions suitable for Nigeria's tropical climate. Thermal comfort in residential buildings has become a critical issue in hot-humid and hot-dry climates due to increasing urbanization, rising temperatures, and growing dependence on mechanical cooling systems. In Nigeria, empirical evidence shows that many residential buildings

fail to provide adequate indoor comfort due to poor ventilation design and suboptimal building configurations. Studies on traditional residential buildings in Nigeria revealed that occupants generally experience thermal conditions ranging from slightly cool to warm, with inadequate ventilation identified as a major contributor to discomfort (Madukwe et al., 2019). Similarly, research in hot-dry regions indicates that building form, orientation, and fenestration significantly affect indoor thermal conditions, with poor airflow associated with occupant discomfort and health challenges (Haruna et al., 2018). These findings emphasize the importance of integrating climate-responsive design strategies into residential buildings. Passive design strategies are widely recognized as sustainable approaches for improving indoor environmental quality while reducing energy demand. In Nigeria, bioclimatic frameworks have been developed to reduce residential energy consumption through climate-responsive design; however, their applicability across different climatic zones remains limited (Ochedi and Taki, 2019).

Systematic evidence confirms that passive design interventions can significantly reduce indoor temperature, decrease cooling loads, and improve thermal comfort hours in residential buildings located in hot climates (Hu, 2024). Nevertheless, the effectiveness of these strategies is highly dependent on local climate conditions, building typology, and implementation quality.

Further studies on adaptive and urban overheating strategies classify passive interventions into urban design, building envelope modifications, insulation improvements, and occupant behavioural adaptations (Afolabi and Adedire, 2023). However, most findings highlight the need for real-world implementation and performance validation of these strategies.

Natural ventilation remains one of the most extensively studied passive cooling techniques in tropical climates. Evidence from Nigerian residential buildings shows that natural ventilation significantly improves indoor thermal comfort and reduces energy consumption, although its integration in multi-storey residential developments remains limited (Adedayo and Lawal, 2023). Empirical studies further confirm that ventilation efficiency is strongly influenced by building orientation, window design, and wind availability, with poor design leading to thermal discomfort and increased reliance on mechanical cooling (Haruna et al., 2018). In low-income housing, improved ventilation has been shown to reduce energy use and enhance comfort levels, although adoption remains inconsistent (Eze and Ehisuoria, 2025).

Experimental research demonstrates that cross ventilation can reduce indoor temperatures by up to 3°C while significantly improving comfort hours in hot climates (Palomo et al., 2025). Additionally, climatic studies confirm that façade design and wind speed are critical factors influencing ventilation performance in tropical residential environments (Wang and Wong, 2007). Green infrastructure has emerged as an important passive cooling strategy in contemporary architecture. In Lagos, residential buildings incorporating vertical greenery systems exhibited reduced heat stress and improved occupant comfort compared to conventional buildings (Joshua and Ayinla, 2025). However, large-scale adoption of such systems remains limited in Nigerian residential developments.

Similarly, studies across urban residential contexts show that passive measures such as shading, orientation control, and ventilation can significantly reduce indoor temperatures, although implementation is often poor in low- and middle-income housing (Zamwawosayi et al., 2025). This highlights a persistent gap between theoretical effectiveness and practical application.

Recent studies have emphasized the role of spatial configuration in shaping thermal comfort conditions. Research in high-density residential environments demonstrates that orientation, openness, wind access, and building morphology significantly influence microclimate conditions,

accounting for over 50% of thermal variation in some cases (Chen et al., 2025; Muhy Al-Din et al., 2023). These findings highlight that spatial design is not only aesthetic but also functional in regulating indoor environmental quality. Building envelope components such as walls, insulation, glazing, and roof systems play a crucial role in controlling heat gain and improving thermal comfort. Simulation-based studies indicate that optimized envelope design can significantly improve thermal lag and reduce indoor temperature fluctuations (Al-Yasiri et al., 2024).

In Nigerian climates, studies confirm that combining roof insulation, reflective materials, and ventilation strategies leads to substantial improvements in indoor thermal comfort and reduced reliance on air-conditioning systems (Xi et al., 2025). Hybrid systems combining passive and mechanical strategies have also demonstrated superior performance compared to single-strategy approaches. Systematic reviews provide strong evidence that passive design strategies can reduce energy consumption by up to 50% while improving thermal comfort and occupant well-being. However, adoption levels remain relatively low in developing countries due to economic, technical, and regulatory constraints (Ogunnaike et al., 2025).

Similarly, global studies highlight the effectiveness of combining traditional vernacular design strategies with modern innovations such as cool roofs, phase-change materials, and parametric design tools to enhance thermal performance in hot climates (Manshour and Lehmann, 2025). Advanced AI-based building control systems have been shown to improve energy efficiency and comfort levels, although real-world application remains limited by data constraints and infrastructure challenges.

A substantial body of literature has established the effectiveness of passive design strategies in improving thermal comfort and enhancing energy efficiency in buildings. For example, Sholanke and Ganya (2024) reported that passive design measures significantly reduce energy consumption and improve environmental performance in tropical climates. Similarly, Oluwarotimi (2026) demonstrated that integrating traditional Nigerian architectural principles with modern passive design approaches can reduce residential energy use by up to 60%, highlighting the importance of orientation, building envelope design, ventilation, and shading strategies.

Despite these contributions, significant gaps remain in the existing literature. Ochedi (2022) revealed persistent thermal discomfort across different residential building typologies in Lokoja, Nigeria, with operative temperatures remaining above acceptable comfort thresholds. However, the study primarily relied on simulation techniques and did not comprehensively assess the extent to which passive design strategies are implemented in actual residential buildings or how occupants perceive their effectiveness. Likewise, Kamaruzzaman et al. (2018) emphasized the importance of indoor environmental quality and residents' satisfaction, particularly regarding ventilation and thermal conditions, but their study was conducted in Malaysia, making its findings difficult to generalize directly to the socio-cultural and climatic conditions of southwestern Nigeria. Furthermore, Abdallah (2022) demonstrated that passive cooling measures such as courtyard design, vegetation, and shading significantly improve thermal comfort in hot climates. Nevertheless, the study focused on educational buildings in Egypt rather than residential buildings, thereby limiting its applicability to housing environments. Similarly, while Oluwarotimi (2026) advocated the integration of traditional and modern passive design principles, the study identified limited incorporation of indigenous Nigerian architectural knowledge into contemporary residential design frameworks.

Therefore, there remains a lack of empirical studies that comprehensively evaluate the application and effectiveness of passive design strategies in residential buildings within Ede, Osun State.

Existing studies have either focused on different climatic regions, different building types, simulation-based assessments, or broader discussions of energy efficiency without adequately examining occupants' thermal comfort experiences in residential settings. Consequently, this study seeks to fill this gap by assessing the passive design strategies employed in residential buildings in Ede and evaluating their effectiveness in enhancing thermal comfort from both building-performance and occupant-perspective dimensions.

2.0 Methodology

This study adopted a mixed-methods research approach combining quantitative measurements and qualitative assessment to evaluate passive design strategies and their influence on thermal comfort in residential buildings in Ede, Osun State, Nigeria. The approach is consistent with previous studies that integrated environmental monitoring, occupant perception surveys, and building performance evaluation to assess indoor thermal conditions (Okafor et al., 2022; Yang et al., 2025). The study area, Ede, is located in the tropical humid climate of southwestern Nigeria, characterized by high temperatures and humidity, which necessitate effective passive cooling strategies for residential comfort. Residential buildings and their occupants constitute the study population. A multistage sampling technique was used to select residential buildings and occupants for assessment. This ensures representation across different housing typologies and neighbourhoods, consistent with similar thermal comfort studies in residential environments (Kamaruzzaman et al., 2018; Yang et al., 2025).

Data were collected using three main instruments: structured questionnaires, building observation checklists, and indoor environmental measurements. The questionnaire captured occupants' thermal sensation, comfort perception, and adaptive behaviour, following established approaches in thermal comfort studies (Yin et al., 2023). The observation checklist assessed passive design features such as building orientation, shading devices, window-to-wall ratio, ventilation openings, roof design, and vegetation, which have been identified as key determinants of thermal performance in residential buildings (Fernandez-Antolin et al., 2019; Elshafei et al., 2021; Bhikhoo et al., 2017). Indoor air temperature and relative humidity were measured using standard digital instruments to determine actual thermal conditions within selected residential spaces. This combined measurement approach aligns with methods used in previous empirical studies on residential thermal comfort (Okafor et al., 2022; Yang et al., 2025). Data analysis involved descriptive statistics such as frequencies, percentages, means, and standard deviation, while inferential statistics including correlation and regression analysis were used to examine relationships between passive design variables and thermal comfort levels. Similar analytical techniques have been widely applied in indoor environmental quality studies (Kamaruzzaman et al., 2018; Yang et al., 2025). Overall, the methodology integrates building performance evaluation and occupant-based assessment to provide a comprehensive understanding of how passive design strategies influence thermal comfort in residential buildings within a tropical Nigerian context.

3.0 Results

The assessment of passive design strategies and thermal comfort in residential buildings in Ede, Osun State reveals a moderate to low level of integration of climate-responsive design principles across the sampled buildings. Findings from field observation indicate that passive strategies are present in varying degrees but are often partially implemented and not optimised for thermal performance. This aligns with existing studies which show that passive design adoption in many

residential environments in Nigeria remains inconsistent despite its proven ability to improve indoor thermal conditions (Ochedi and Taki 2019; Abdulkareem and Al-Maiyah 2025).

To provide a clear foundation for interpretation, Table 1 presents a synthesis of relevant literature on passive design and thermal comfort while Table 2 presents the field-based audit results from Ede residential buildings.

Table 1: Summary of Key Studies on Passive Design and Thermal Comfort

Author(s)	Year	Context	Key Passive Strategy	Main Finding
Abdulkareem and Al-Maiyah	2025	Abuja, Nigeria	Integrated passive design in housing prototypes	~20% reduction in thermal discomfort during peak heat
Palomo et al.	2025	Spain (Historic building)	Shading, glazing, insulation, ventilation optimization	Up to 3% reduction in discomfort hours
Madukwe et al.	2019	Nigeria (traditional Igbo housing)	Vernacular passive design	Acceptable thermal sensation but limited ventilation
Hailu et al.	2021	Ethiopia (hot-arid climate)	Traditional vs modern design	88% satisfaction in traditional vs 22% in modern buildings
Ochedi and Taki	2019	Nigeria	Energy-efficient/passive design adoption	Low adoption due to awareness and regulatory gaps
Bello et al.	2025	Bauchi Metropolis, Nigeria	Shading, orientation control	Poor implementation; shading enhances comfort
Rana	2021	Global tropical regions	Multi-passive integration (shading, insulation, window profiles)	Up to 50% reduction in discomfort hours when combined with natural ventilation

Source: Author's compilation based on literature review (2019–2025)

Table 2: Field-Based Passive Design Audit of Residential Buildings in Ede (n = 40)

Passive Design Parameter	Fully Present n (%)	Partially Present n (%)	Absent n (%)	Interpretation
Building orientation	14 (35.0%)	18 (45.0%)	8 (20.0%)	Poor climatic alignment
Natural ventilation	22 (55.0%)	12 (30.0%)	6 (15.0%)	Moderate airflow design
Window-to-wall ratio	10 (25.0%)	16 (40.0%)	14 (35.0%)	Poor envelope control
Shading devices	15 (37.5%)	14 (35.0%)	11 (27.5%)	Inconsistent shading
Roof insulation	8 (20.0%)	10 (25.0%)	22 (55.0%)	Very low adoption

Wall materials	16 (40.0%)	18 (45.0%)	6 (15.0%)	Moderate thermal quality
Courtyards	6 (15.0%)	9 (22.5%)	25 (62.5%)	Rare integration
Vegetation	11 (27.5%)	13 (32.5%)	16 (40.0%)	Limited microclimate control
Ceiling height	19 (47.5%)	15 (37.5%)	6 (15.0%)	Fair vertical airflow
Operable windows	20 (50.0%)	14 (35.0%)	6 (15.0%)	Moderate adaptive ventilation

Source: Field survey and author building audit checklist Ede 2026

The field results indicate that natural ventilation is the most widely implemented passive design strategy among the surveyed residential buildings, whereas roof insulation and courtyard-based design are the least adopted features. This finding suggests that most residential buildings in Ede rely primarily on basic ventilation measures rather than a comprehensive integration of passive design strategies for thermal comfort enhancement.

4.0 Discussion

The findings are consistent with the study of Abdulkareem and Al-Maiyah (2025), which reported that the application of passive design strategies in Nigerian residential buildings remains inadequate and fragmented, thereby limiting their overall effectiveness in reducing thermal discomfort. Similarly, Palomo et al. (2025) observed that substantial improvements in thermal comfort and indoor temperature reductions of up to 3°C are achieved when passive cross-ventilation strategies are properly optimized. Furthermore, Rana (2021) demonstrates that a up to 50% reduction in discomfort hours can be accomplished when multiple passive interventions such as shading, insulation, and window profiles are integrated seamlessly within a naturally ventilated building framework. The limited adoption of advanced passive design features observed in the study area may also be attributed to broader challenges within the Nigerian construction sector. According to Ochedi and Taki (2019), factors such as low public awareness, weak regulatory enforcement, economic constraints, and inadequate adoption of climate-responsive technologies continue to hinder the implementation of energy efficient building practices across the country. Furthermore, the present findings corroborate the works of Madukwe et al. (2019) and Hailu et al. (2021), who found that traditional residential buildings generally provide better thermal performance than many contemporary buildings due to their inherent passive design characteristics, including enhanced natural ventilation, appropriate building orientation, thermal mass utilisation, and adaptation to local climatic conditions.

Overall, the residential buildings assessed in Ede exhibit a transitional level of passive design adoption, where basic ventilation measures are relatively common, but more advanced climate-responsive strategies remain underutilised. This underscores the need for greater integration of passive design principles in residential architecture to improve thermal comfort, reduce energy consumption, and promote sustainable housing development in tropical environments.

5.0 Conclusion

The study assessed the application of passive design strategies for thermal comfort in residential buildings in Ede, Osun State. The findings revealed that natural ventilation is the most commonly adopted passive strategy, while roof insulation, courtyard design, and landscape-based cooling measures are less frequently incorporated. The results indicate that although some passive design

elements are present, their overall integration remains inadequate for achieving optimal thermal comfort and energy efficiency.

Based on the findings, architects and building designers should prioritise the incorporation of climate responsive passive design strategies such as proper building orientation, effective shading devices, roof insulation, cross ventilation, and landscape planning in residential developments. Government agencies and professional bodies should also strengthen awareness programmes and building regulations that encourage the adoption of sustainable and energy efficient housing practices. Increased implementation of passive design strategies will contribute to improved indoor thermal comfort, reduced energy consumption, and enhanced environmental sustainability.

Future studies should examine the long-term performance of passive design strategies through continuous monitoring and building performance simulation. Research could also compare thermal comfort in traditional and contemporary residential buildings across different climatic regions of Nigeria. In addition, attention should be given to occupant behaviour, socioeconomic conditions, housing density, sustainable materials, emerging passive technologies, and hybrid cooling methods to better understand their effects on thermal comfort and energy use in tropical homes.

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