
ASSESSMENT OF PASSIVE DESIGN STRATEGIES FOR THERMAL COMFORT IN TROPICAL RESIDENTIAL BUILDINGS OGBOMOSO, OYO STATE, NIGERIA.

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Abstract:

Rapid urbanization and rising temperatures in tropical regions have increased the need for climate-responsive residential buildings that provide thermal comfort while reducing dependence on mechanical cooling systems and mitigating greenhouse gas emissions. The growing preference for thermally inappropriate modern construction materials, compact layouts, and inadequate ventilation in contemporary housing further exacerbates indoor heat gain and reduces thermal comfort. Therefore, this study evaluates the effectiveness of passive design strategies for enhancing thermal comfort across selected residential building typologies in Ogbomosho, Nigeria.

A mixed-method approach was adopted, combining a structured questionnaire survey of 307 residents with field measurements of air temperature, relative humidity, air velocity, and heat stress index. Descriptive statistics were used to analyze occupants' perceptions of thermal comfort and the prevalence of passive design strategies, while environmental measurements assessed the thermal performance of different residential building typologies.

The findings indicate that natural ventilation and external shading were the most widely adopted passive design strategies, although their implementation varied across residential zones. Duplex buildings exhibited the most favorable thermal conditions, recording the highest air velocity (0.8 m/s), the lowest indoor air temperature (29.1°C), and the lowest relative humidity (60%). In contrast, Brazilian (face-me-I-face-you) buildings recorded the poorest thermal performance, with the highest indoor temperature (31.5°C), relative humidity (68%), and a heat index of approximately 40°C, indicating a high level of thermal stress.

The study concluded that building typology significantly influences the effectiveness of passive design strategies and indoor thermal comfort and that integrating climate-responsive passive design principles into residential planning and housing development can substantially improve occupant comfort and reduce cooling energy demand in tropical environments.

Keywords: Passive design strategies, thermal comfort, climate-responsive architecture; Residential buildings.

1.0 Introduction

Buildings account for approximately 30% of global final energy consumption and 26% of energy-related greenhouse gas emissions, making the building sector one of the largest contributors to global climate change (Elnagar et al., 2024). Residential buildings constitute a significant share of this energy demand, largely due to the increasing reliance on mechanical cooling systems to maintain acceptable indoor thermal comfort under rising ambient temperatures. These challenges underscore the urgent need for sustainable approaches that improve the thermal performance of residential buildings while reducing energy consumption and environmental impacts.

The challenge is particularly pronounced in tropical regions, where persistently high temperatures, elevated humidity, and intense solar radiation adversely affect indoor environmental quality and thermal comfort (Satterthwaite et al., 2020; Ramsay et al., 2021). Rapid urbanization has further intensified urban overheating through increased impervious surfaces, reduced vegetation, and restricted natural ventilation. Consequently, passive design strategies have emerged as sustainable and cost-effective approaches for improving indoor thermal comfort while reducing dependence on mechanical cooling systems.

Nigeria, like many tropical African countries, is experiencing rapid urbanization and increasing demand for residential housing. Historically, residential buildings incorporated climate-responsive passive design features that moderated indoor thermal conditions. However, contemporary housing development has increasingly shifted towards standardized building forms with limited consideration of local climatic conditions, resulting in greater dependence on mechanical cooling systems (Dimuna et al., 2025). This transition has increased residential energy demand and intensified environmental concerns, reinforcing the need to re-integrate passive design principles into housing design to promote thermally comfortable, energy-efficient, and climate-responsive residential environments (Randazzo et al., 2020; Auffhammer, 2022).

Despite the recognized benefits of passive design strategies, many residential buildings in Ogbomoso experience thermal discomfort, particularly during the dry and transitional seasons, due to inadequate adaptation to local climatic conditions. Previous studies have shown that many residential buildings in Nigeria lack sufficient climate-responsive design features, while the increasing adoption of modern construction materials, compact building layouts, and inadequate natural ventilation has further reduced indoor thermal performance (Adaji, 2019; Awoyera et al., 2024).

Studies on passive design and thermal comfort have been conducted in major Nigerian cities such as Lagos, Ibadan, and Abuja (Onyenokporo, 2019), limited empirical evidence exists for medium-sized cities such as Ogbomoso. Furthermore, little attention has been given to the combined influence of residential building typology, neighborhood density, passive design strategies, and measured thermal comfort within a single analytical framework. Addressing this gap is essential for developing context-specific, climate-responsive housing strategies for tropical urban environments. This study therefore assesses passive design strategies for thermal comfort in tropical residential buildings focusing on building typologies, their implementation, and their influence on indoor thermal conditions across different residential density zones.

2.0 Literature Review

2.1 Thermal Comfort in Residential Buildings

Thermal comfort is a fundamental consideration in residential building design because it directly influences occupants' health, well-being, productivity, and overall quality of life. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (2023), thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment." This definition highlights the subjective nature of thermal comfort, as occupants exposed to the same indoor environment may perceive thermal conditions differently due to variations in physiological, psychological, and behavioral characteristics. Thermal comfort is achieved when the human body maintains thermal equilibrium through heat exchange with its surroundings by radiation, convection, conduction, and evaporation (Guler et al., 2023; Kenny et al., 2024).

According to Özbey and Turhan (2022), thermal comfort is determined by six primary variables comprising two personal factors—metabolic rate and clothing insulation—and four environmental factors—air temperature, mean radiant temperature, air velocity, and relative humidity. Personal factors influence the amount of heat generated and retained by the human body, while environmental factors influence the rate of heat exchange between occupants and their surroundings. In naturally ventilated residential buildings, air temperature, relative humidity, and air velocity are particularly important because they directly influence occupants' thermal perception and adaptive responses. These environmental parameters, together with occupants' clothing insulation and activity level, formed the basis for assessing thermal comfort conditions in the present study.

Several thermal comfort indices have been developed to evaluate indoor environmental conditions. Traditional indices include the Effective Temperature (ET), Corrected Effective Temperature (CET), and Operative Temperature (OT). Recent studies increasingly adopt the adaptive thermal comfort approach for naturally ventilated buildings because it accounts for occupants' behavioral adaptation to local climatic conditions (Arsad et al., 2023).

The foregoing discussion demonstrates that thermal comfort results from the interaction between occupants and their surrounding environment. In tropical climates, achieving acceptable indoor thermal conditions depends largely on the integration of climate-responsive passive design strategies capable of reducing indoor heat gain, improving natural ventilation, and enhancing occupants' comfort without excessive reliance on mechanical cooling. This provides the theoretical foundation for examining passive design strategies as an effective means of improving thermal comfort in residential buildings.

2.2 Passive Design for Thermal Comfort

Passive design is a climate-responsive approach to building design that utilizes natural environmental resources to achieve acceptable indoor thermal conditions while minimizing dependence on mechanical heating and cooling systems. Unlike active design, which relies on energy-intensive technologies such as air-conditioning and mechanical ventilation, passive design employs architectural features including building orientation, natural ventilation, shading, thermal mass, and appropriate material selection to regulate indoor environmental conditions (Saleem, 2024). Although the concept has existed throughout the history of vernacular architecture, it has gained renewed importance in contemporary sustainable building design due to growing concerns about climate change, rising energy demand, and environmental sustainability (Kritika, 2021).

The primary objective of passive design is to maintain thermal comfort by responding appropriately to local climatic conditions rather than resisting them through mechanical means. In hot-humid tropical climates, Studies have shown that incorporating passive design measures can substantially reduce cooling loads, improve building energy performance, and lower operational costs while maintaining acceptable indoor thermal conditions (Gil-Ozoudeh et al.,2022). This is achieved by integrating climate-responsive design principles during the early stages of building planning and design, thereby enhancing indoor environmental quality while reducing energy consumption (Bilal, 2024).

The effectiveness of passive design depends on the appropriate application of climate-responsive architectural strategies suited to the local environment. These include building orientation, compact building form, natural ventilation, external shading, vegetation, and the selection of suitable building materials. Understanding these strategies is essential for evaluating their contribution to thermal comfort in residential buildings and provides the basis for the discussion presented in the subsequent section.

2.3 Passive Design Strategies for Thermal Comfort

Passive design strategies are climate-responsive architectural measures that improve indoor thermal comfort by minimizing heat gain, enhancing natural ventilation, and utilizing natural environmental resources to reduce reliance on mechanical cooling systems. Their effectiveness depends on the local climate, building characteristics, and the integration of these strategies during the design stage (Allam, 2019; Gil-Ozoudeh et al., 2022). The principal passive design strategies relevant to residential buildings are discussed below:

i. Building Orientation

Building orientation determines how a building interacts with solar radiation and prevailing winds. In tropical climates, orienting the longer building axis in the east–west direction reduces exposure to intense morning and afternoon solar radiation while allowing the main façades to face north and south (Aste et al., 2020). Proper orientation also facilitates cross-ventilation and daylight penetration, thereby reducing indoor heat gain and improving thermal comfort with lower energy demand (Rode et al., 2021; Gil-Ozoudeh et al., 2022).

ii. Building Form and Layout

Building form influences the amount of heat transferred through the building envelope. Compact forms reduce the surface-area-to-volume ratio, thereby limiting heat gain and improving thermal performance (Araji, 2019). Appropriate internal space planning, including locating frequently occupied spaces on cooler façades and arranging rooms to facilitate airflow, further enhances passive cooling and indoor comfort (Manshour& Lehmann, 2026).

iii. Natural Ventilation

Natural ventilation is one of the most effective passive cooling strategies in warm-humid climates. It relies on wind-driven and buoyancy-driven airflow through appropriately positioned openings to remove excess heat and improve indoor air quality (Cuce et al., 2019). Cross-ventilation is particularly effective because it promotes continuous air movement, enhances convective heat loss, and reduces dependence on mechanical cooling (Jiang, 2023).

iv. Shading Devices

Shading devices reduce solar heat gain by limiting direct solar radiation on walls, roofs, and windows. Roof overhangs, verandas, canopies, and external louvers provide

effective protection against overheating while maintaining adequate daylight (Gil-Ozoudeh et al., 2022). In tropical regions, shading east- and west-facing façades is particularly important because they receive the highest solar intensity during the day.

v. Roof Design and Roofing Materials

The roof receives the greatest amount of solar radiation in tropical climates and therefore plays a major role in indoor thermal performance. Reflective roofing materials, insulated roofs, ventilated roof spaces, and extended roof overhangs reduce heat transfer into buildings, resulting in lower indoor temperatures and improved occupant comfort (Gil-Ozoudeh et al., 2022).

vi. Vegetation and Landscaping

Vegetation contributes to passive cooling by shading buildings, reducing surrounding surface temperatures, and cooling the air through evapotranspiration (Hu et al., 2023). Proper landscaping also improves the residential microclimate by directing airflow and minimizing heat reflected from surrounding surfaces, thereby enhancing outdoor and indoor thermal comfort.

vii. Building Materials, Thermal Insulation and Buffer Spaces

The thermal characteristics of building materials significantly influence indoor temperatures. Materials with appropriate thermal resistance, combined with thermal insulation, reduce heat transfer through the building envelope (Gil-Ozoudeh et al., 2022). Buffer spaces such as verandas, balconies, courtyards, and service areas provide transitional zones that reduce direct solar exposure and improve natural ventilation. The combined application of these measures enhances passive cooling and promotes thermal comfort in residential buildings.

3.0 Methodology

3.1 Study Area

This study was conducted in Ogbomoso, Oyo State, Nigeria. A town with a rapidly growing urban center located in the tropical climatic zone of southwestern Nigeria. Three neighborhoods representing the predominant residential density classifications within the study area were purposively selected. These comprised Masifa (high-density residential area), Stadium Area (medium-density residential area), and Oke-Afin (low-density residential area) as shown in Figure 1. The selected neighborhoods exhibit differences in urban morphology, residential building typologies, plot configuration, and environmental characteristics, making them suitable for evaluating the implementation and effectiveness of passive design strategies across varying residential settings.

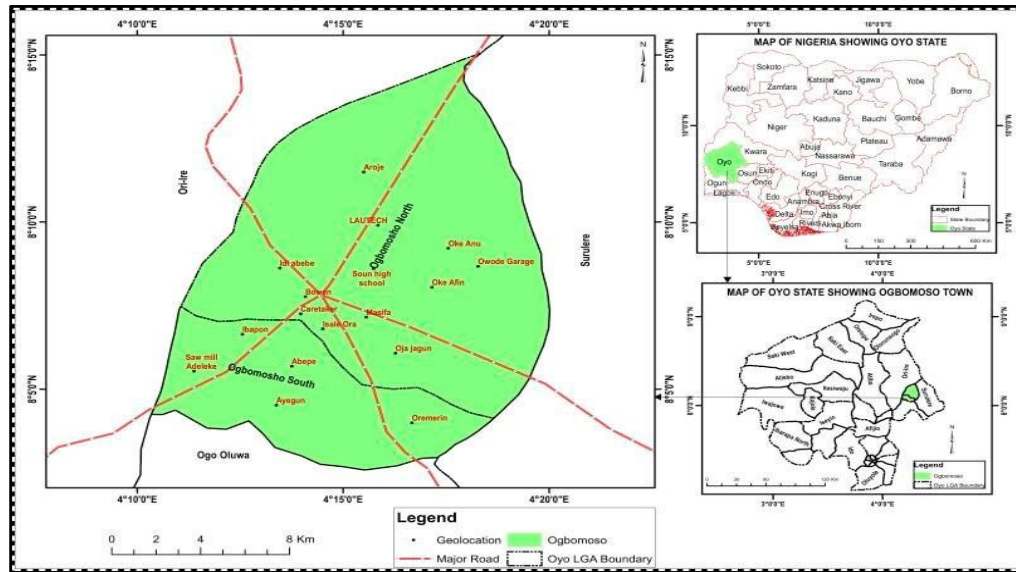


Figure 1: Map of Ogbomoso
Source: Mustapha, 2023

3.2 Research Design

This study adopted a multi-stage sampling techniques research design to assess passive design strategies and their influence on thermal comfort in residential buildings. It enabled the collection of occupants' perceptions, field observations, and environmental measurements at a single point in time, thereby enabling comparative analysis across different residential density zones.

The study population comprised of 1,680 residential buildings distributed across the selected neighborhoods, consisting of 1,020 buildings in Masifa, 528 buildings in Stadium Area, and 132 buildings in Oke-Afin. Each residential building represented a household unit from which one respondent was selected.

The sample size was determined using the Slovin formula, which is appropriate for estimating representative samples from finite populations:

n = Sample size; N = Total population (1,680 residential buildings); e = Margin of error (0.05)

$$n = 1680 / (1 + 1680(0.05)^2)$$

$$n = 1680 / (1 + 4.2); n = 1680 / (5.2); n = 323$$

3.3 Sampling frame and Sample size

The calculated sample size of 323 represented approximately 19.2% of the total population of 1,680 residential buildings. The sample was proportionally distributed across the three selected residential density zones based on the number of the building zone.

Table 1: Sampling frame and Sampling size

S/N	Density zones	Selected Area	Estimated No. Of buildings	Percentage (19.2%)
1	High-density	Masifa	1,020	196
2	Medium-density	Stadium	528	102
3	Low-density	Oke-afin	132	25
	TOTAL		1,680	323

Source: Author's Compilation (2025)

A purposive sampling technique was initially employed to classify residential buildings according to residential density. Thereafter, simple random sampling was used to select the sampled residential buildings within each stratum. The required number of buildings were selected from the sample frame randomly without any predetermined order until the desired sample size was obtained. The buildings were not chosen in a predetermined order because they aren't uniformly arranged. The sample comprised 196 residential buildings in Masifa, 102 in Stadium Area, and 25 in Oke-Afin.

3.4 Data collection and Data analysis

Primary data were collected through structured questionnaires, field observations, and on-site environmental measurements. The questionnaire obtained information on respondents' socio-demographic characteristics, residential building characteristics, occupants' perception of indoor thermal comfort, and the passive design features incorporated in their dwellings. Field observations verified the presence of building orientation, natural ventilation provisions, shading devices, vegetation, roofing materials, and building spacing.

Indoor environmental measurements were carried out using a Kestrel 4400 Heat Stress Tracker, to obtain air temperature (°C), relative humidity (%), and air velocity (m/s). Measurements were taken using a consistent procedure across all sampled residential buildings to ensure comparability of the environmental data. A total of 323 questionnaires were administered, of which 307 were successfully retrieved and found suitable for analysis, representing a 95.0% response rate. Participation was voluntary, with informed consent obtained and response treated confidentially academic purposes.

The collected data were analyzed using descriptive statistical including frequencies, percentages, means, tables, charts, and graphs. Environmental measurement was analyzed using Heat Stress Index to access indoor thermal comfort conditions. Comparative analysis was conducted across the three residential density zones, with results presented using tables and figures.

4.0 Findings and Discussion

4.1 Climatic Characteristics of Ogbomoso in Relation to Thermal Comfort

The climatic characteristics of Ogbomoso were analyzed to establish the environmental conditions influencing thermal comfort in residential buildings. Climatic variables such as air temperature, relative humidity, rainfall, and prevailing wind direction where examined, while the Mahoney Tables were used to translate the climatic conditions into design recommendation for climate-responsive residential buildings.

a. Air Temperature

Air temperature is a primary determinant of indoor thermal comfort because it influences heat transfer between the building envelope and its occupants. As shown in Figure

2, the mean monthly maximum temperature in Ogbomoso ranged from 29.26°C in August to 34.42°C in March, while the mean monthly minimum temperature varied between 14.24°C in January and 22.22°C in April.

The annual mean temperature was approximately 28.89°C, reflecting the persistently warm conditions. The highest temperature occurred between February and April, while relatively lower temperature was recorded during the rainy season. However, daytime temperature remained sufficiently high to create potential overheating, highlight the need for shading, appropriate orientation, and natural ventilation.

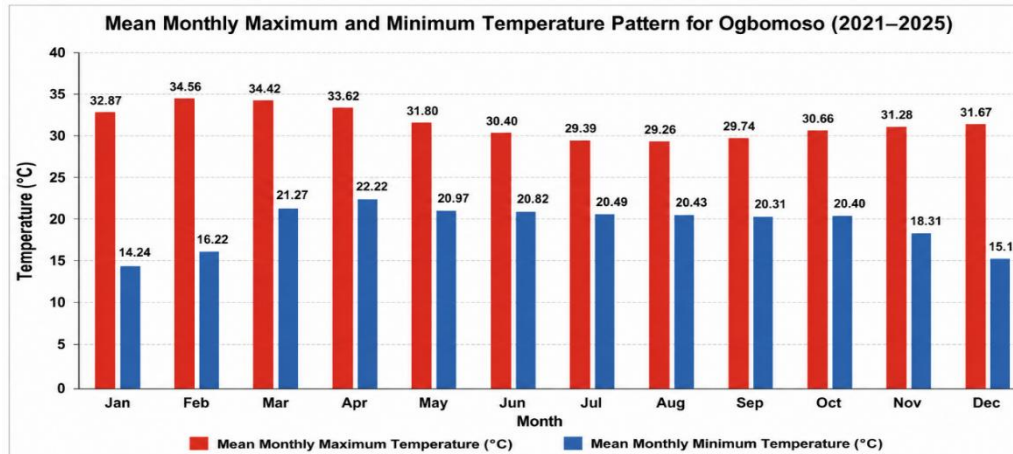


Figure 2: Monthly mean maximum and minimum air temperatures in Ogbomoso.

b. Relative Humidity

Relative humidity influences occupants' thermal sensation by affecting the rate of evaporative heat loss from the human body. Figure 3 shows that the mean monthly relative humidity ranged from 67.26% in January to 89.82% in August. Humidity levels increased during the rainy season, and remained relatively high between July and September, and gradually declined towards the dry season. The combination of high humidity and elevated temperatures can reduce evaporative cooling and increase thermal discomfort, particularly in poorly ventilated buildings. This emphasizes the importance of adequate air movement and cross-ventilation.

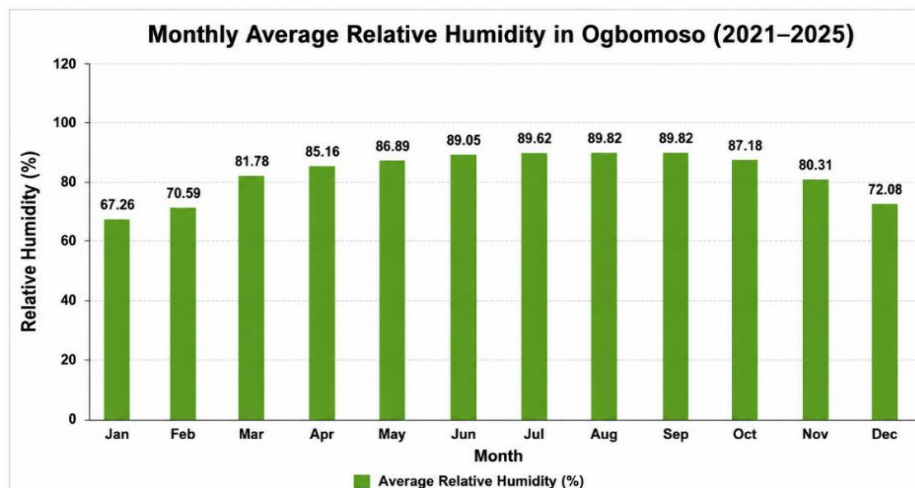


Figure 3: Monthly average relative humidity in Ogbomoso.

c. Rainfall Pattern

Ogbomoso experienced approximately 1,007 mm of annual rainfall. As shown in Figure 4, rainfall is concentrated between April and October, reaching a peak of approximately 193 mm in August. It contributes to lower ambient temperatures during the wet season but also increases atmospheric humidity. Buildings therefore require adequate roof overhangs and weather-protected openings to support natural ventilation while preventing rain penetration.

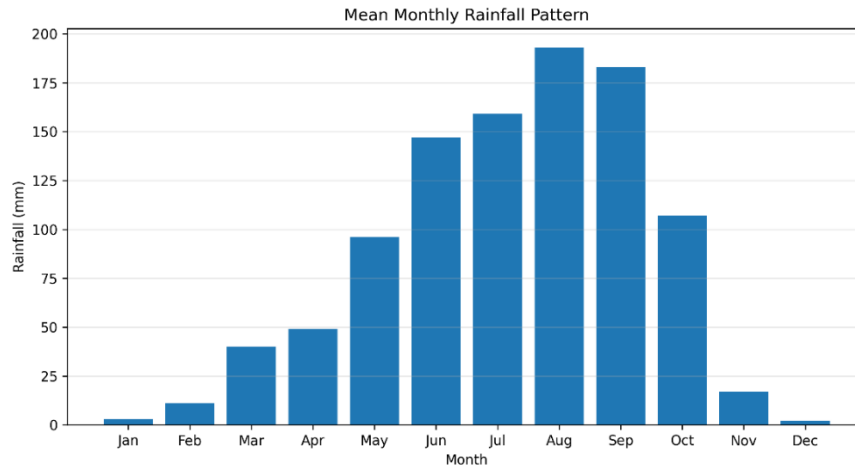


Figure 4: Monthly rainfall distribution in Ogbomoso.

d. Prevailing Wind Direction

Prevailing wind direction is an important climatic factor influencing natural ventilation and indoor thermal comfort. The Mahoney analysis indicates that north-easterly (NE) winds predominate during the dry season, whereas south-westerly (SW) winds prevail during the rainy season. These seasonal wind patterns provide opportunities for enhancing natural ventilation through appropriate building orientation and the strategic placement of openings. Maximizing exposure to prevailing breezes can improve air temperature and enhance thermal comfort.

e. Mahoney Climatic Analysis and Design Implications

The Mahoney climatic diagnosis indicates that Ogbomoso experiences persistent daytime thermal stress throughout most months, while night-time conditions are generally more favorable, with only limited periods of mild cool stress during the early dry seasons. The combination of high temperatures and relative high humidity further emphasizes the need for effective air movement in residential building.

The resulting design recommendations include appropriate buildings orienting, providing adequate spacing, single-banked room layouts that promote cross-ventilation, incorporating large and appropriately positioned openings, using lightweight wall construction with short thermal lightweight insulated roofs to reduce heat transmission. The recommendations also emphasized the need for adequate roof overhangs and rain protection measures to allow continuous natural ventilation during the rainy season.

Overall, the climatic analysis establishes a strong basis for evaluation passive design strategies and their relationship with indoor thermal comfort in the sampled residential buildings

4.2 Residential Building Typologies in the Study Area

The residential building typologies identified across the three selected neighborhoods reflect differences in urban density, housing characteristics, and opportunities for passive environmental design within Ogbomoso. Figure 5 illustrates the distribution of residential building typologies across the high-density (Masifa), medium-density (Stadium Area), and low-density (Oke-Afin) residential neighborhoods.

Compound houses were the predominant housing type in Masifa (60.2%), followed by Brazilian-style houses (30.1%) and bungalows (9.7%). Their compact layouts, characterized by limited setbacks and closely spaced buildings, are likely to restrict natural ventilation and daylight penetration, thereby increasing indoor heat accumulation. In the medium-density Stadium Area, bungalows (31.5%), Brazilian-style houses (30.9%), and self-contained apartments (26.8%) were the dominant housing types, reflecting a transition from traditional to contemporary residential development. Compared with Masifa, the lower building density provides better opportunities for natural ventilation and passive cooling. Conversely, the low-density Oke-Afin neighborhood was dominated by bungalows (41.6%), self-contained apartments (37.5%), and duplexes (20.8%), which are generally associated with larger plot sizes, adequate setbacks, and improved integration of passive design features such as cross-ventilation, external shading, and landscape elements.

Overall, the results indicate that residential building typology is a key determinant of passive environmental performance in tropical residential environments. Housing forms associated with lower residential density offer greater potential for climate-responsive design and improved thermal comfort while reducing reliance on mechanical cooling systems.

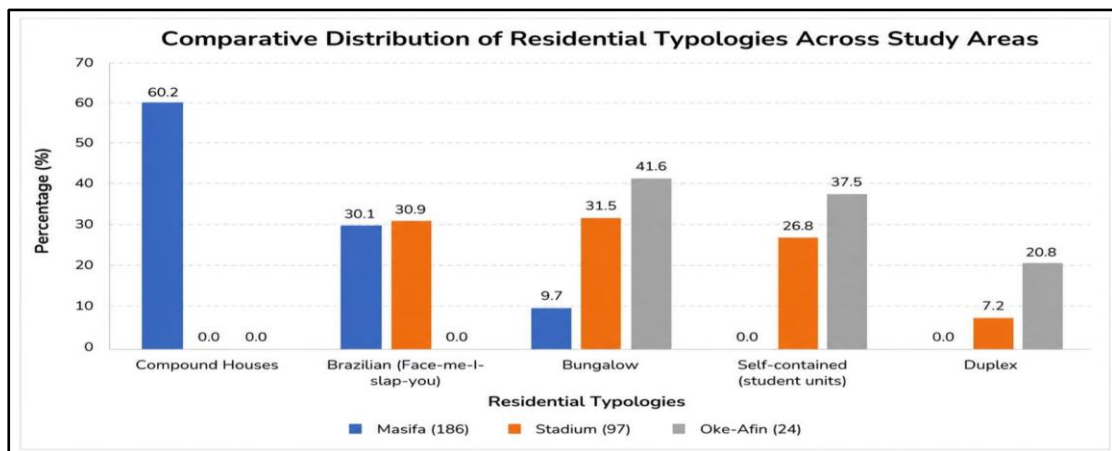


Figure 5: Distribution of residential building typologies across the selected residential neighborhoods.

4.3 Passive Design Strategies Adopted in Residential Buildings

The adoption of passive design strategies varied across the three residential density zones. The assessed strategies included building orientation, natural ventilation, shading devices, vegetation, thermal insulation, thermally efficient roofing materials, and buffer spaces. Figure 6 presents their distribution across the selected neighborhoods.

In Masifa, shading devices (69.9%) and natural ventilation (60.2%) were the most widely adopted strategies, while vegetation (32.7%) and thermally efficient roofing materials (36.2%) recorded the lowest adoption. In Stadium Area, natural ventilation had the highest adoption rate (75.5%), followed by shading devices (63.7%), while building orientation and

thermal insulation recorded 61.8% each. Oke-Afin recorded the highest overall adoption, with thermal insulation at 92.0% and building orientation, natural ventilation, thermally efficient roofing materials, and buffer spaces at approximately 88.0%.

The results reveal a progressive increase in the adoption of passive design strategies from the high-density to the low-density neighborhoods. This trend suggests that lower residential density, improved plot configuration, and contemporary housing development provide greater opportunities for incorporating climate-responsive design features that enhance natural ventilation, reduce solar heat gain, and improve indoor thermal conditions.

These findings are consistent with previous studies. Adaji (2019) reported that the limited integration of passive design strategies in many Nigerian residential buildings contributes to poor indoor thermal performance and increased reliance on mechanical cooling. Similarly, Awoyera et al. (2024) observed that contemporary residential developments generally provide better opportunities for incorporating passive design measures such as appropriate building orientation, adequate building spacing, and natural ventilation.

Overall, the findings highlight the importance of incorporating passive design principles at the planning and building-design stages, particularly in high-density residential developments. The relationship between passive design adoption and measured indoor thermal conditions is examined in the subsequent section.

Table 2: Distribution of Passive Design Strategies Across Residential Zones

Passive Strategy	Masifa (n=186)	Stadium (n=97)	Oke-Afin (n=24)
Orientation (N-S)	82 (41.8%)	63 (61.8%)	22 (88.0%)
Natural Ventilation	118 (60.2%)	77 (75.5%)	22 (88.0%)
Shading Devices	137 (69.9%)	65 (63.7%)	20 (80.0%)
Roofing Materials (Thermal Efficiency)	71 (36.2%)	54 (52.9%)	22 (88.0%)
Thermal Insulation (Ceiling)	84 (42.9%)	63 (61.8%)	23 (92.0%)
Vegetation	64 (32.7%)	52 (51.0%)	21 (84.0%)
Buffer Spaces (Veranda/Balcony)	96 (49.0%)	61 (59.8%)	22 (88.0%)

Source: Author's Field Survey, 2026.

4.4 Evaluation of Thermal Comfort Conditions in Selected Residential Buildings

This section evaluates the thermal comfort conditions of selected residential buildings in Ogbomoso based on occupants' personal variables and measured indoor environmental parameters. The personal variables provide information on occupants' adaptive characteristics, the environmental variables offer objective evidence of the thermal performance of the selected residential building typologies.

i. Personal Variables Influencing Thermal Comfort

The personal variables considered in this study include gender, age, activity level, and clothing insulation, as presented in Figure 6 and Figure 7. Female respondents constituted 57.0% of the sample, while 42.9% were male. The majority of respondents (59.0%) were between 21 and 40 years.

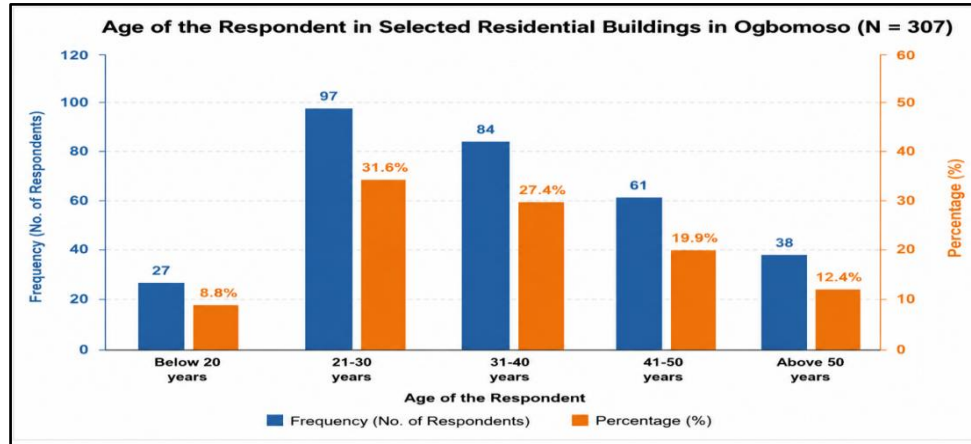


Figure 6: Gender and Age Distribution

Regarding activity level, 45.5% of respondents were seated (1.1 met), 29.4% were walking (1.7 met), 13.0% were standing (1.2 met), 6.8% were running (3.8 met), while 5.3% were sleeping (0.8 met) during the survey (Figure 5). In terms of clothing insulation, 43.0% wore light clothing (0.3 clo), 39.7% wore moderate clothing (0.5 clo), and 17.2% wore heavy clothing (0.7 clo).

The predominance of seated activities and light clothing provides important context for interpreting the measured indoor thermal conditions, as lower metabolic activity and lighter clothing influence occupants' thermal responses. The environmental measurements are therefore examined alongside these personal variables in subsequent analysis.

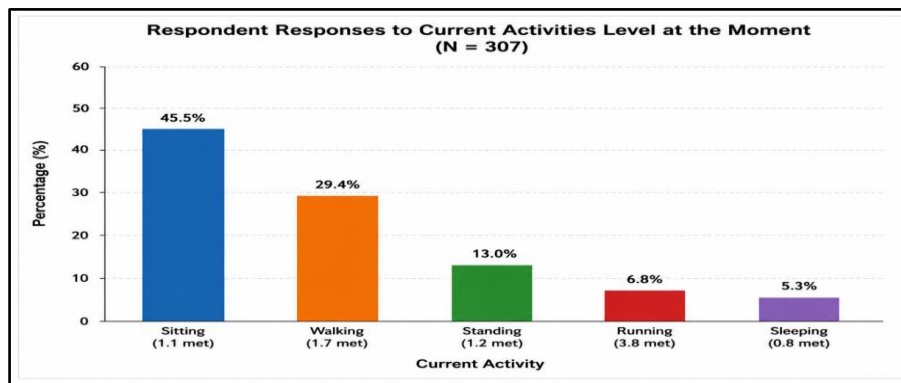


Figure 7: Occupants' activity levels during the field survey.

4.5 Environmental Variables Influencing Thermal Comfort

ii. Air Velocity

Measured indoor air velocity ranged from 0.4 m/s in Brazilian houses to 0.8 m/s in duplexes, while flats, bungalows, and traditional compound houses recorded 0.7, 0.6, and 0.5 m/s, respectively as shown in Figure 8. The higher air velocities recorded in duplexes and flats indicate more effective indoor air movement, potentially associated with greater building

spacing, larger openings, and improved exposure to prevailing winds. Conversely, the lower values in Brazilian and traditional compound houses suggest more restricted airflow due to their relatively compact layouts and limited ventilation pathways.

The findings support ASHRAE Standard 55 (2020), which recognizes increased air movement as an important mechanism for enhancing thermal comfort through convective and evaporative heat loss. They also align with Awoyera et al. (2024), who found that adequate spacing, favorable orientation, and effective natural ventilation contribute to improved thermal performance in tropical residential buildings.

Overall, the air velocity results demonstrate the importance of natural ventilation and building configuration in improving indoor thermal conditions. The pattern also corresponds with the higher adoption of passive design strategies observed in the lower-density residential area.

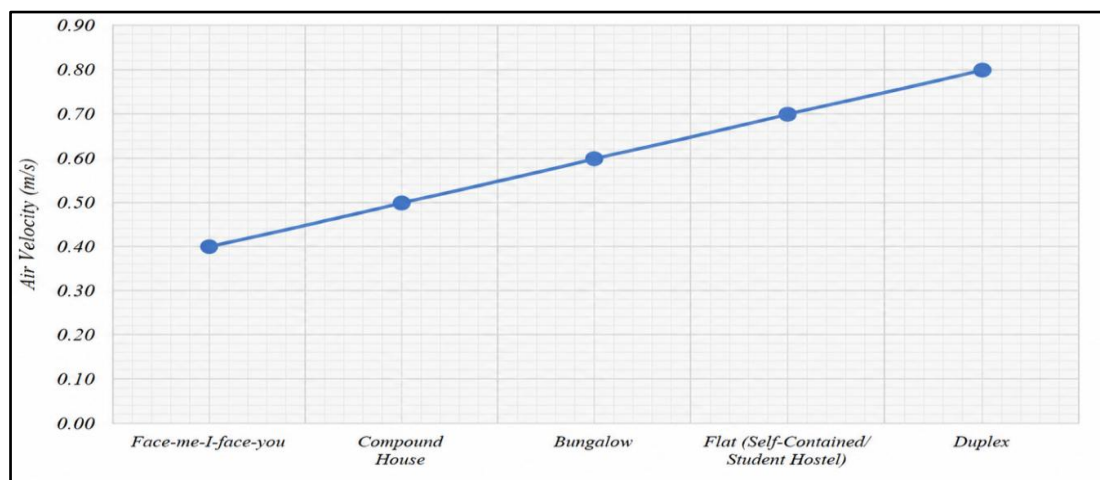


Figure 8: Indoor air velocity

iii. Air Temperature and Relative Humidity

The measured indoor air temperature and relative humidity across the selected residential building typologies. Indoor air temperature ranged from 29.1°C in duplex buildings to 31.5°C in Brazilian houses. As shown in Figure 9, Flats, bungalows, and traditional compound houses recorded temperatures of 29.8°C, 30.2°C, and 30.5°C, respectively. Similarly, as shown in figure 10, relative humidity ranged from 60% in duplex buildings to 68% in Brazilian houses, while flats, bungalows, and traditional compound houses recorded values of 62%, 64%, and 65%, respectively.

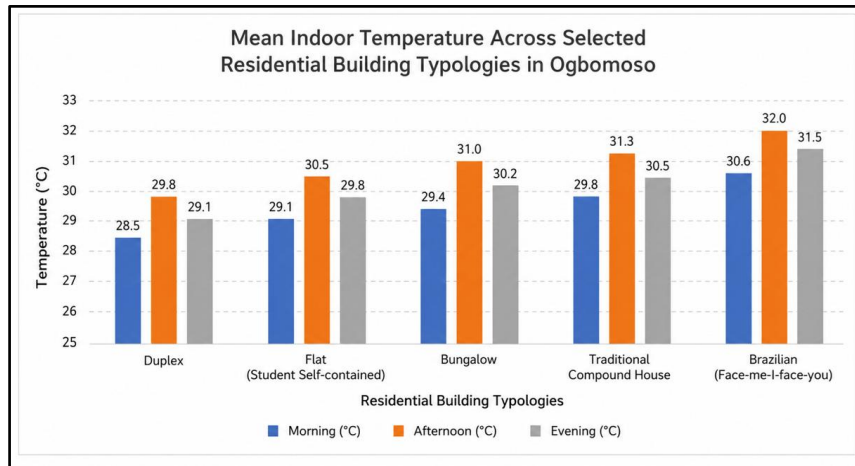


Figure 9: Mean Indoor Temperature across selected residential building typologies

Duplexes recorded the lowest temperature and relative humidity, indicating more favorable indoor thermal conditions, while Brazilian houses recorded the highest values. The differences may be associated with variations in building spacing, orientation, openings, and natural ventilation. Higher humidity can also reduce evaporative heat loss, potentially increasing thermal discomfort under warm conditions.

Overall, the results indicate that building typology and passive design integration significantly influence different indoor thermal conditions with duplexes indicating more favorable conditions than the other typologies.

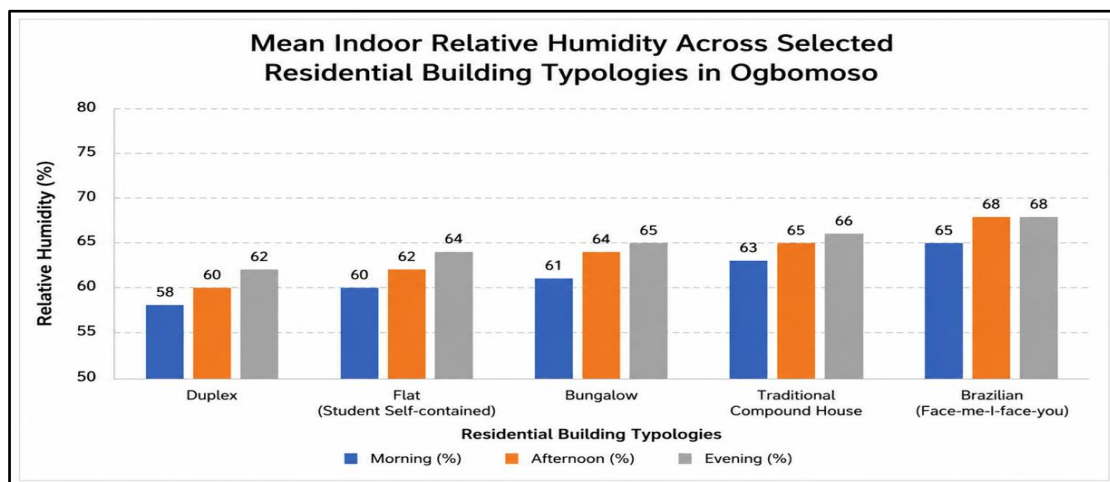


Figure 10: Mean indoor relative humidity across selected residential building typologies

iv. Heat Stress Index

The Heat Stress Index (HSI) values are presented in Figure 11. Duplexes recorded the lowest HSI (31°C), classified as “Caution.” Flats (33°C), bungalows (35°C), and traditional compound houses (36.52°C) fell within the “Extreme Caution” category, while Brazilian houses recorded the highest HSI (40°C), classified as “Danger.”

The increasing HSI from duplexes to Brazilian houses corresponds with differences in indoor temperature, relative humidity, and air velocity. Buildings with lower temperatures

and humidity and higher air movement recorded lower heat stress, while typologies with more restricted ventilation experienced greater thermal stress.

Overall, the results indicate that residential buildings with greater integration of passive design measures, including appropriate orientation, adequate spacing, natural ventilation, and solar shading, achieved more favorable thermal conditions than those with limited passive design integration. This highlights the importance of climate-responsive design in improving thermal comfort and reducing reliance on mechanical cooling in tropical residential buildings.

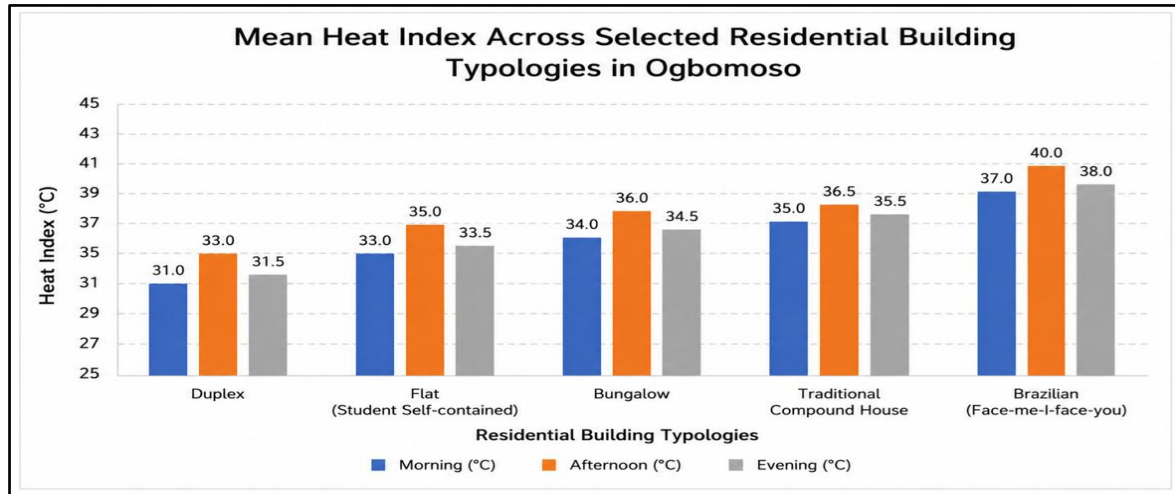


Figure 11: Heat Stress Index across selected residential building typologies in Ogbomoso.

5.0 Conclusion

This study concluded that passive design strategies significantly improve thermal comfort in residential buildings in Ogbomoso's tropical climate. Climatic analysis identified appropriate building orientation, natural ventilation, external shading, adequate building spacing, and thermally efficient building materials as key strategies for reducing indoor heat gain. Residential buildings with greater integration of these passive design measures, particularly in low-density neighborhoods, exhibited lower indoor temperatures, higher air velocities, and reduced heat stress than those in high-density areas.

The findings confirm that building typology and the extent of passive design implementation strongly influence indoor thermal performance. Therefore, integrating climate-responsive passive design principles into residential planning and housing development offers a practical approach to enhancing occupant comfort while reducing dependence on mechanical cooling in tropical environments.

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