

Assessment of Passive Design Strategies for Improving Thermal Comfort in High-Rise Condominiums in Yola, Nigeria

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Abstract

Thermal discomfort is a major challenge in high-rise residential buildings located in hot tropical climates, leading to increased reliance on mechanical cooling systems and higher energy consumption. This study assessed passive design strategies for improving thermal comfort in high-rise condominium developments in Yola, Adamawa State, Nigeria. A mixed-method approach was adopted, combining a questionnaire survey of built-environment professionals with a comparative analysis of selected local and international case studies. A total of 235 valid responses were analyzed using descriptive statistical techniques. The findings revealed strong agreement among respondents regarding the importance of passive design strategies in enhancing thermal comfort. Indoor space quality (Mean = 4.20), landscaping (Mean = 4.16), and the use of local materials (Mean = 4.15) emerged as the most highly rated design strategies for importance. When evaluating perceived practical effectiveness, horizontal overhangs (Mean = 4.29), the effect of occupant behavior (Mean = 4.21), and site orientation (Mean = 4.19) were identified as the most effective interventions. The comparative case study analysis of Eko Pearl Towers, World Trade Center Abuja, Bosco Verticale, and One Central Park demonstrated that successful thermal performance depends on integrating multiple passive strategies, including climate-responsive orientation, efficient façade design, landscape elements, natural ventilation, and vegetation-based cooling systems. The study concludes that integrating passive design strategies can significantly improve thermal comfort, reduce dependence on air-conditioning systems, lower operational energy consumption, and promote sustainable housing development in tropical environments. It recommends the adoption of climate-responsive design principles and stronger consideration of passive environmental strategies in future high-rise residential developments in Nigeria.

Keywords: *Passive design strategies; Thermal comfort; High-rise condominiums; Natural ventilation; Building orientation; Solar shading; Sustainable architecture; Yola, Nigeria.*

1.0 Introduction

Rapid urbanization and population growth have increased the demand for high-density residential developments across many cities worldwide. High-rise condominiums have emerged as an effective response to land scarcity and urban housing shortages, particularly in rapidly expanding metropolitan areas. These developments offer opportunities for efficient land utilization and sustainable urban growth while accommodating increasing population densities (Ajibola et al., 2024; Zhou & Herr, 2023). Thermal comfort is a critical determinant of occupant health, productivity, and overall building performance. In hot climatic regions,

maintaining acceptable indoor thermal conditions often requires significant energy expenditure through mechanical cooling systems. Such dependence on air-conditioning contributes to increased operational costs, higher energy consumption, and greater environmental impacts. Consequently, there is growing interest in passive design strategies capable of enhancing indoor thermal comfort while reducing reliance on energy-intensive cooling technologies (Anand et al., 2023). Passive design strategies utilize natural environmental resources such as solar radiation, wind movement, vegetation, and material thermal properties to regulate indoor conditions without excessive mechanical intervention. Common passive design measures include building orientation, natural ventilation, solar shading devices, thermal mass utilization, high-performance building envelopes, and landscape integration. Previous studies have demonstrated that appropriately integrated passive strategies can significantly reduce cooling loads while improving occupant comfort and environmental sustainability (Ogunsote & Prucnal, 2020; Chen & Wang, 2022). The application of passive design is particularly relevant in Yola, Adamawa State, Nigeria. Located within the Sudan Savannah climatic zone, Yola experiences prolonged periods of high temperatures, intense solar radiation, and seasonal climatic extremes. These environmental conditions expose buildings to substantial thermal stress, often resulting in indoor overheating and increased demand for artificial cooling systems. The challenge is further compounded by Nigeria's persistent electricity supply constraints, which limit the effectiveness and affordability of mechanically conditioned indoor environments. Studies conducted in comparable climatic regions have shown that climate-responsive design measures can substantially improve indoor thermal performance. Heidari et al. (2024) demonstrated that integrated systems enhancing natural ventilation significantly reduce cooling loads and improve thermal comfort in residential buildings. Similarly, Ibrahim and Freewan (2023) established that optimized solar shading devices substantially reduce solar heat gain and improve energy efficiency on exposed building facades while maintaining adequate daylight penetration. Within the Nigerian context, Danjuma et al. (2025) established that specific building forms and orientation techniques that enhance natural ventilation and light are critical for improving indoor environmental quality during occupied periods. Despite the growing body of knowledge on passive thermal design, much of the existing literature focuses on low-rise residential buildings or developments located in tropical and temperate regions. Limited empirical evidence exists regarding the suitability and effectiveness of passive design strategies in high-rise condominium developments within the Sudan Savannah region of Nigeria. Furthermore, many contemporary high-rise residential developments continue to prioritize economic and aesthetic considerations over climatic responsiveness, resulting in buildings with substantial cooling energy requirements. This gap in knowledge presents a challenge for architects, planners, and developers seeking to implement climate-responsive residential developments in Yola and similar semi-arid environments. There is therefore a need to identify the passive design strategies most suitable for enhancing thermal comfort in high-rise condominiums and to evaluate their potential contributions to sustainable residential development. Accordingly, this study assesses passive design strategies for improving thermal comfort in high-rise condominiums in Yola, Nigeria. Specifically, the study identifies applicable passive design measures, evaluates their effectiveness in enhancing thermal performance, examines lessons from selected local and international case studies, and proposes recommendations for integrating passive design principles into future high-rise residential developments. The findings are expected to contribute to the advancement of climate-responsive architecture, sustainable housing delivery, and energy-efficient building design in Nigeria and other regions with similar climatic characteristics.

2.0 Literature Review

2.1 Concept of Thermal Comfort

Thermal comfort refers to a condition of mind that expresses satisfaction with the surrounding thermal environment. It is a critical indicator of building performance because it directly influences occupants' health, well-being, productivity, and overall quality of life. Contemporary thermal comfort research recognizes that occupants' perception of comfort is influenced by environmental variables such as air temperature, relative humidity, air movement, mean radiant temperature, clothing insulation, and metabolic activity. In naturally ventilated buildings, occupants often demonstrate adaptive responses (such as physiological, behavioral, and psychological adjustments) that allow them to tolerate a wider range of indoor temperatures than those predicted by conventional static comfort models.

Field studies conducted within the Nigerian built environment have shown that building users can adapt to and accept elevated indoor temperatures approaching 30°C when adequate natural ventilation, air movement, and behavioral controls are provided (Adaji et al., 2020; Adekunle & Nikolopoulou, 2016). This high adaptive capacity highlights the vital importance of climate-responsive design approaches in warm, semi-arid regions like the Sudan Savannah. Consequently, thermal comfort extends far beyond rigid temperature regulation to encompass the creation of indoor environments that actively support occupant adaptation and satisfaction while minimizing operational energy consumption.

2.2 Passive Design Strategies in High-Rise Residential Buildings

Passive design strategies involve the deliberate use of architectural and environmental design measures to regulate indoor thermal conditions without excessive dependence on mechanical systems. These strategies are increasingly recognized as essential components of sustainable high-rise residential development due to their ability to improve thermal performance, reduce energy consumption, and enhance occupant well-being. Building orientation remains one of the most fundamental passive design measures. Appropriate orientation reduces direct solar heat gain while maximizing exposure to prevailing winds for natural ventilation. In hot climatic regions, buildings oriented to minimize east-west solar exposure generally experience lower cooling loads and improved indoor thermal conditions. Natural ventilation further enhances thermal comfort by facilitating air movement through occupied spaces, reducing heat accumulation and improving occupant perception of comfort. Studies have demonstrated that cross-ventilation and stack-effect ventilation, when optimized through proper building form and orientation, can significantly reduce cooling requirements in residential buildings located in warm climates (Danjuma et al., 2025; Almazmumi et al., 2025). Solar shading devices constitute another important passive cooling strategy. Horizontal overhangs, vertical fins, balconies, recessed windows, and external louvers reduce solar radiation entering building interiors while maintaining daylight availability. Optimized shading systems have been shown to substantially reduce solar heat gain and improve overall thermal performance of building envelopes (Ibrahim & Freewan, 2023; Brzezicki, 2024). In high-rise developments, façade design plays a critical role in controlling heat transfer due to the extensive exposure of vertical surfaces to solar radiation. The thermal properties of building materials also influence indoor comfort conditions. Materials with high thermal mass absorb and store heat during periods of high outdoor temperature and release it gradually when ambient temperatures decrease. When combined with night-time ventilation, thermal mass can moderate indoor temperature fluctuations and improve occupant comfort. High-performance glazing, reflective surfaces, insulated walls, and efficient roofing systems further contribute to reducing unwanted heat gain and improving building energy performance (Ali et al., 2024; Al-Tamimi et al., 2024).

Vegetation-based strategies such as green roofs, green walls, landscaped courtyards, and sky gardens have gained prominence in contemporary high-rise architecture. These elements improve thermal performance through shading, evapotranspiration, and microclimatic modification. Beyond their thermal benefits, green infrastructure contributes to environmental sustainability, biodiversity enhancement, and improved occupant well-being. Evidence from both local and international studies suggests that integrating vegetation into building design can significantly improve thermal comfort while reducing reliance on mechanical cooling systems (Ojobo & Nimlyat, 2024; Milani et al., 2025).

2.3 Theoretical Framework

This study is anchored on Bioclimatic Architecture Theory, which emphasizes the adaptation of building design to local climatic conditions in order to achieve occupant comfort and environmental efficiency (Olgyay, 1963). Developed primarily through the foundational work of Victor Olgyay (1963), the theory advocates the systematic integration of climatic variables (such as solar radiation, temperature, humidity, and wind patterns) into the architectural design process. The central premise is that buildings should respond dynamically to their environmental context rather than depend predominantly on mechanical systems to achieve indoor comfort (Olgyay, 1963). The theory is particularly relevant to the climatic conditions of Yola, where high temperatures and intense solar radiation create significant thermal challenges for residential buildings. By emphasizing orientation, shading, ventilation, thermal mass, and landscape integration, Bioclimatic Architecture Theory provides a robust, scientifically backed framework for evaluating passive design strategies capable of enhancing thermal comfort in high-rise condominiums.

2.4 Empirical Review

Extensive literature consistently demonstrates the effectiveness of passive design strategies in improving indoor thermal conditions and reducing building energy demand (Arowoia et al., 2024; Niza et al., 2022). Research conducted within the Nigerian built environment (specifically in Abuja) has revealed that passive cooling measures such as natural ventilation, building orientation, shading devices, and thermal mass significantly improve thermal comfort in residential buildings while reducing dependence on mechanical cooling systems (Adaji et al., 2020). Similar findings have been reported in studies examining high-rise residential developments, where integrated passive design measures, such as climate-responsive façades, contributed to lower indoor temperatures and improved occupant satisfaction (Ajibola et al., 2024). Recent studies focusing on the built environment indicate a growing professional recognition of passive design as an effective approach to achieving thermal comfort. Architects and design professionals emphasize that optimizing building material efficiency and thermal mass properties are critical measures for enhancing thermal performance, suggesting increasing awareness of climate-responsive design approaches (Obi-George et al., 2024).

International evidence similarly supports the adoption of passive cooling strategies in warm climatic regions. Studies conducted in arid and tropical environments demonstrate that integrated passive measures (such as advanced façade systems and optimized daylighting) produce greater thermal benefits than isolated interventions (Al-Tamimi et al., 2024; Altomonte, 2008). The literature therefore indicates that combining orientation, ventilation, solar control, thermal mass, and vegetation creates a synergistic effect capable of significantly improving indoor thermal conditions while minimizing operational energy requirements (Babiarz et al., 2024).

2.5 Research Gap

Although numerous studies have examined passive design and thermal comfort in residential buildings, most existing research focuses on low-rise housing developments or buildings located in tropical and temperate climatic regions. Comparatively limited attention has been given to high-rise condominium developments within the Sudan Savannah climatic zone of Nigeria. Furthermore, existing studies often evaluate individual passive strategies independently rather than examining their combined effectiveness in enhancing thermal comfort within high-rise residential environments.

The scarcity of empirical evidence specific to Yola creates uncertainty regarding the most suitable passive design strategies for high-rise residential developments under local climatic conditions. Consequently, there remains a need for research that identifies applicable passive design measures, evaluates their effectiveness, and provides context-specific recommendations for integrating passive thermal design into high-rise condominium development. This study addresses this gap by assessing passive design strategies for improving thermal comfort in high-rise condominiums in Yola, Nigeria.

3.0 Methodology

3.1 Research Design

This study adopted a mixed-method research design to assess passive design strategies for improving thermal comfort in high-rise condominiums in Yola, Nigeria. The mixed-method approach was considered appropriate because it enabled the integration of quantitative and qualitative data, thereby providing a comprehensive understanding of the effectiveness and applicability of passive design measures in enhancing indoor thermal comfort. Quantitative data were obtained through a questionnaire survey administered to built-environment professionals, while qualitative data were generated from case study analyses, field observations, and a review of relevant literature. The integration of these approaches facilitated the triangulation of findings and strengthened the reliability of the study.

3.2 Study Area

The study was conducted in Yola, the capital city of Adamawa State, Nigeria. Yola is situated within the Sudan Savannah climatic zone and is characterized by high temperatures, intense solar radiation, low relative humidity during the dry season, and seasonal rainfall patterns. Average daytime temperatures frequently exceed 35°C during the hottest months of the year, resulting in considerable thermal stress within buildings. These climatic characteristics make Yola an appropriate location for investigating passive design strategies aimed at improving thermal comfort and reducing dependence on mechanical cooling systems in residential developments.

3.3 Population and Sampling Technique

The study targeted construction professionals and stakeholders involved in the planning, design, construction, and management of buildings within Adamawa State. The target respondents included architects, builders, quantity surveyors, engineers, urban planners, project managers, and other built-environment professionals with relevant knowledge and experience in building design, environmental performance, and thermal comfort considerations. Due to the absence of a comprehensive and up-to-date database of construction professionals actively practicing within Adamawa State, the study population could not be accurately enumerated. Furthermore, many professionals working on construction projects in the state are engaged on a project basis and may not be permanent residents of the study area.

Consequently, a purposive sampling technique was adopted to identify respondents possessing relevant expertise and practical experience related to building design and construction. Questionnaires were distributed through professional networks, construction firms, project sites, government agencies, and institutional contacts within the built environment sector. A total of 248 questionnaires were administered to eligible respondents. Out of this number, 235 questionnaires were properly completed and returned, representing a response rate of 94.8%. The 235 valid responses formed the basis for the quantitative analysis and were considered adequate for achieving the objectives of the study.

3.4 Sources of Data

Both primary and secondary data sources were utilized in this study.

Primary data were obtained through a structured questionnaire survey administered to selected respondents, eliciting information on the suitability, effectiveness, and implementation of passive design strategies.

Secondary data were obtained from peer-reviewed journal articles, conference proceedings, textbooks, technical reports, climate records, building performance studies, and documented case studies. These sources provided theoretical and empirical foundations for the study and informed the interpretation of the findings.

3.5 Data Collection Instrument

A structured questionnaire served as the primary instrument for data collection. The questionnaire consisted of two sections. The first section captured the demographic and professional characteristics of the respondents, including profession, educational qualification, years of experience, and involvement in high-rise building projects. The second section contained statements relating to passive design strategies and their effectiveness in improving thermal comfort in high-rise residential buildings.

The questionnaire items were measured using a five-point Likert scale ranging from Strongly Agree (5) to Strongly Disagree (1). This scale enabled respondents to express their perceptions regarding the relevance and effectiveness of various passive design measures, including building orientation, natural ventilation, shading devices, thermal mass, insulation systems, façade treatments, green roofs, and green walls.

3.6 Case Study Selection

To complement the questionnaire survey, a comparative case study approach was adopted. The selected case studies comprised both international and Nigerian high-rise developments that demonstrate the successful application of passive design principles in enhancing thermal comfort and environmental performance.

The selection of case studies was guided by the following criteria:

- i. Relevance to high-rise residential development.
- ii. Integration of passive design strategies.
- iii. Demonstrated climatic responsiveness.
- iv. Environmental and operational performance.
- v. Potential applicability to the climatic conditions of Yola.

Based on these criteria, the selected case studies included Bosco Verticale (Milan, Italy), One Central Park (Sydney, Australia), Eko Pearl Towers (Lagos, Nigeria), and the World Trade Center (Abuja, Nigeria). Each case study was evaluated in terms of building orientation, natural ventilation strategies, façade design, shading systems, material selection, landscape integration, and passive cooling measures.

3.7 Data Analysis Techniques

Quantitative data obtained from the questionnaire survey were analyzed using descriptive statistical techniques. Frequencies, percentages, mean scores, and standard deviations were used to summarize respondents' opinions regarding the effectiveness of passive design strategies in enhancing thermal comfort. Mean score analysis was employed to rank the identified passive design measures according to their perceived effectiveness. Higher mean scores indicated stronger levels of agreement among respondents regarding the suitability and effectiveness of a particular strategy. Qualitative data obtained from the literature review, field observations, and case study analyses were analyzed using thematic and comparative techniques. Similar patterns, design features, and passive cooling approaches identified across the selected case studies were compared and synthesized to generate context-specific recommendations for high-rise condominium developments in Yola. The results obtained from both quantitative and qualitative analyses were integrated during the discussion stage to provide a comprehensive assessment of passive design strategies capable of improving thermal comfort in high-rise residential buildings within the Sudan Savannah climatic region of Nigeria.

4.0 Results and Discussion

4.1 Respondents' Characteristics

Table 4.1: Socio-Economic and Demographic Information

Variable	Category	Frequency (N=235)	Percentage (%)
Gender	Male	145	61.7%
	Female	90	38.3%
Age	16-20	12	5.1%
	21-25	48	20.4%
	26-30	85	36.2%
	31-35	60	25.5%
	Others	30	12.8%
Qualification	HND	45	19.1%
	B.Sc	95	40.4%
	M.Sc	75	31.9%
	Ph.D	12	5.1%
	Others	8	3.4%
Experience	1-5 Years	90	38.3%
	6-10 Years	70	29.8%
	11-15 Years	40	17.0%
	16-20 Years	25	10.6%
	Others	10	4.3%
High-Rise Exp.	Yes	110	46.8%
	No	125	53.2%

Source: Field Survey 2026.

A total of 235 valid responses were obtained and analyzed. The demographic profile of respondents indicates that 61.7% were male, while 38.3% were female. The majority of respondents (36.2%) were between 26 and 30 years of age, followed by those within the 31–35 age category (25.5%). Regarding educational qualifications, 40.4% possessed a Bachelor's degree, 31.9% held Master's degrees, and 5.1% possessed doctoral qualifications. This indicates that the respondents possessed adequate academic and professional knowledge to evaluate passive design strategies for thermal comfort enhancement.

In terms of professional experience, 38.3% had between one and five years of experience, while 29.8% had between six and ten years of experience. Although only 46.8% of respondents had direct experience with high-rise building projects, the respondents collectively represented a knowledgeable group of built-environment professionals capable of providing informed opinions on passive design applications in residential developments.

4.2 Assessment of Passive Design Strategies

The findings reveal strong agreement among respondents regarding the importance of passive design strategies in improving thermal comfort in high-rise condominium developments as shown below in table 4.2. Calculations are based on a 5-point Likert scale (SA=5, A=4, U=3, D=2, SD=1) with N=235 for all items.

Table 4.2: Analysis of Passive Design Strategies

Table 4.2: Corrected Analysis of Passive Design Strategies

S/N	Item Description	SA	A	U	D	SD	True Mean	True Std. Dev
1	Building orientation improves indoor thermal comfort	95	103	15	16	6	4.13	0.98
2	Passive envelope materials reduce indoor heat gain	96	84	29	15	11	4.02	1.10
3	Daylighting improves indoor comfort and visibility	98	93	20	11	13	4.07	1.09
4	Natural ventilation improves indoor air movement	94	97	24	9	11	4.08	1.04
5	Landscaping reduces surrounding temperature	90	110	22	8	5	4.16	0.88
6	Thermal comfort standards improve performance	105	82	27	13	8	4.12	1.04
7	Insulation materials reduce heat penetration	94	92	29	9	11	4.06	1.05
8	Passive glazing designs improve thermal comfort	89	91	32	9	14	3.99	1.10
9	Sun shading devices reduce direct solar heat	89	94	20	14	18	3.94	1.18
10	Indoor space quality improves comfort	109	87	23	8	8	4.20	0.99
11	Building mass affects temperature regulation	81	102	25	16	11	3.96	1.07
12	Indoor air quality affects comfort levels	89	102	21	11	12	4.04	1.06
13	Green roofs improve cooling performance	91	97	25	9	13	4.04	1.07
14	Green walls reduce indoor heat gain	83	106	25	10	11	4.02	1.03
15	Local materials improve passive cooling	99	99	20	7	10	4.15	0.99
16	Rainwater collection supports sustainability	104	85	25	11	10	4.11	1.05

17	Grey water recycling improves sustainability	99	91	24	12	9	4.10	1.03
18	Sensors improve energy efficiency	96	90	29	9	11	4.07	1.05
19	Grey air refreshing improves environmental quality	100	84	27	15	9	4.07	1.07

Source: Field Survey 2026.

All evaluated variables recorded mean scores ranging from 3.94 to 4.20 on a five-point scale, indicating a solid baseline of acceptance among professionals. Indoor space quality emerged as the highest-rated variable, recording a mean score of 4.20. This was closely followed by landscaping (Mean = 4.16), the use of local materials (Mean = 4.15), building orientation (Mean = 4.13), and thermal comfort standards (Mean = 4.12).

Other highly ranked variables included resource-efficiency measures such as rainwater collection (Mean = 4.11) and grey water recycling (Mean = 4.10), alongside natural ventilation (Mean = 4.08), daylighting, sensor-assisted energy management, and grey air refreshing (each recording a Mean = 4.07). Insulation materials (Mean = 4.06), indoor air quality and green roofs (both Mean = 4.04), and passive envelope materials and green walls (both Mean = 4.02) also received favorable ratings. The lowest-ranked strategies were passive glazing designs (Mean = 3.99), building mass considerations (Mean = 3.96), and sun-shading devices (Mean = 3.94). Although these specific strategies recorded comparatively lower mean values, the overall results indicate substantial support for integrating ecological and resource-efficient features into future developments. The findings demonstrate that respondents prioritize fundamental spatial quality, site-level interventions (such as landscaping), and the use of local materials as the most critical components for improving thermal comfort under the hot climatic conditions of Yola, while placing slightly less emphasis on specific solar control additions.

All evaluated variables recorded mean scores above 4.29 on a five-point scale, indicating a high level of acceptance among professionals.

Building orientation and natural ventilation emerged as the highest-rated passive design strategies, each recording a mean score of 4.487. These were closely followed by sun-shading devices (Mean = 4.480), passive glazing systems (Mean = 4.470), indoor space quality (Mean = 4.453), indoor air quality (Mean = 4.447), and passive envelope materials (Mean = 4.440). Other highly ranked variables included insulation materials (Mean = 4.433), daylighting strategies (Mean = 4.430), building mass considerations (Mean = 4.420), and sensor-assisted energy management systems (Mean = 4.407).

Green roofs (Mean = 4.350), landscaping (Mean = 4.357), grey-water recycling (Mean = 4.343), rainwater harvesting (Mean = 4.337), green walls (Mean = 4.307), and the use of local materials (Mean = 4.290) also received favourable ratings. Although these strategies recorded comparatively lower mean values, the results indicate substantial support for integrating ecological and resource-efficient features into future high-rise developments.

The findings demonstrate that respondents perceive passive cooling measures, solar control strategies, and climate-responsive architectural features as essential components for improving thermal comfort under the hot climatic conditions of Yola.

4.3 Perceived Effectiveness of Passive Design Strategies

Calculations are based on a 5-point Likert scale with N=235 for all items.

Table 4.3: Effectiveness of Passive Design Strategies

S/N	Item Description	VE (5)	E (4)	NSE (3)	NE (2)	NAE (1)	True Mean	True Std. Dev
1	Site orientation improves comfort	117	76	22	10	10	4.19	1.05
2	Shading devices reduce heat gain	121	65	25	13	11	4.16	1.12
3	Natural ventilation performance	112	83	15	11	14	4.14	1.12
4	Thermal mass stability	120	69	20	13	13	4.15	1.14
5	Daylighting quality	127	66	15	14	13	4.19	1.14
6	Insulation performance	127	64	12	17	15	4.15	1.20
7	High-performance glazing	110	74	32	10	9	4.13	1.05
8	Occupant behavior effect	122	70	23	10	10	4.21	1.06
9	Passive design education	111	75	29	9	11	4.13	1.08
10	Cultural sensitivity	106	77	24	14	14	4.05	1.15
11	Climate considerations	114	61	31	16	13	4.05	1.18
12	Horizontal overhangs	126	71	22	13	3	4.29	0.94
13	Vertical overhangs	116	66	32	12	9	4.14	1.08

Source: Field Survey 2026

The effectiveness assessment further confirmed the importance of passive environmental design in enhancing thermal comfort, though the hierarchy of effective strategies shifts when evaluated in practice.

Horizontal overhangs were ranked as the most effective physical strategy (Mean = 4.29), closely followed by the effect of occupant behavior (Mean = 4.21). Site orientation and daylighting quality also recorded high effectiveness scores (both Mean = 4.19), emphasizing the critical role of positioning and spatial arrangement before active interventions are applied. General shading devices (Mean = 4.16), thermal mass stability (Mean = 4.15), and insulation performance (Mean = 4.15) formed the next tier of highly rated strategies. Natural ventilation performance and vertical overhangs (both Mean = 4.14) were also perceived as effective, though they did not dominate the rankings as initially expected.

Broader conceptual factors, including passive design education and high-performance glazing (both Mean = 4.13), cultural sensitivity (Mean = 4.05), and generalized climate considerations (Mean = 4.05), recorded the lowest mean values, though they still indicate general effectiveness. The results suggest that professionals in the hot tropical climate of northeastern Nigeria perceive concrete, physical interventions (specifically structural overhangs and site orientation) alongside active occupant engagement, as more immediately effective than generalized climate concepts or passive ventilation alone.

4.4 Lessons from Case Studies

The comparative analysis of Eko Pearl Towers, Bosco Verticale, One Central Park, and the World Trade Center Abuja revealed several recurring passive design principles that contribute significantly to thermal comfort and energy efficiency.

Across all case studies, building orientation, natural ventilation, external shading devices, efficient façade design, and landscape integration were identified as fundamental passive design strategies. The Nigerian case studies demonstrated the practical application of orientation, balconies, solar shading devices, and landscaped open spaces to reduce heat gain and improve occupant comfort. In contrast, the international case studies expanded these approaches through extensive integration of vertical greenery systems, vegetated façades, and innovative environmental technologies. Bosco Verticale and One Central Park particularly demonstrated the thermal benefits of façade greening systems, which reduce solar heat gain through shading and evapotranspiration while simultaneously improving urban biodiversity and environmental quality. Eko Pearl Towers and the World Trade Center illustrated how climate-responsive planning, natural ventilation, and solar protection measures can effectively improve thermal performance within the Nigerian context. The comparative findings indicate that optimal thermal performance is achieved through the integration of multiple passive strategies rather than reliance on a single design intervention.

4.5 Discussion of Findings

The study confirms that passive design strategies are critical for improving thermal comfort in high-rise condominium developments located in hot climatic regions. The consistently high mean scores recorded across the assessed variables indicate strong professional consensus regarding the importance of climate-responsive architecture in reducing indoor heat gain and improving occupant comfort. However, the results refine conventional assumptions by revealing that professionals prioritize fundamental indoor space quality, site-level landscaping, and the use of local materials over generalized interventions like passive glazing or generic sun-shading devices. This reinforces the argument that thermal comfort is fundamentally rooted in holistic spatial quality and site-level environmental conditioning before relying on localized building envelope additions. Furthermore, when evaluating practical application, physical and structural interventions (specifically horizontal overhangs) alongside site orientation and occupant behavior, emerged as the most effective measures. This demonstrates that passive cooling in the Sudan Savannah climate requires robust, fixed architectural elements and an active understanding of human interaction with the space. Proper orientation combined with heavy structural shading reduces heat accumulation, thereby decreasing dependence on mechanical air-conditioning systems. The findings further demonstrate the growing relevance of green infrastructure in contemporary high-rise developments. Respondents expressed strong support for green roofs, green walls, landscaping, and other nature-based solutions capable of improving thermal performance and environmental sustainability. Lessons derived from Bosco Verticale and One Central Park suggest that integrating vegetation directly into building envelopes can substantially improve thermal comfort while contributing to broader environmental benefits. The study also highlights the importance of material selection, insulation systems, and high-performance glazing in regulating heat transfer through the building envelope. These measures enhance indoor thermal stability and support energy-efficient building operation under extreme climatic conditions. Finally, stakeholder engagement, climate-data utilization, sustainability considerations, and digital performance assessment tools were identified as critical success factors influencing the implementation of passive design strategies. The findings therefore suggest that future high-rise condominium developments in Yola should adopt an integrated passive design approach that combines targeted structural shading, orientation, spatial quality optimization, and landscape-based solutions to achieve improved thermal comfort, reduced energy consumption, and long-term environmental sustainability.

5.0 Conclusion and Recommendations

5.1 Conclusion

This study assessed passive design strategies for improving thermal comfort in high-rise condominium developments in Yola, Adamawa State, Nigeria. The study was motivated by the increasing challenges associated with high temperatures, rising energy consumption, and growing dependence on mechanical cooling systems within residential buildings located in hot tropical climates. Through a combination of questionnaire surveys and comparative case study analysis, the research examined the effectiveness of passive design measures and identified strategies suitable for enhancing thermal comfort while promoting sustainable residential development. The findings revealed a strong consensus among built-environment professionals regarding the importance of passive design strategies in achieving comfortable indoor environments. All evaluated passive design variables recorded high mean scores, indicating broad acceptance of climate-responsive architectural solutions as effective mechanisms for improving thermal performance in high-rise residential buildings. Crucially, fundamental indoor space quality, landscaping, the use of local materials, and building orientation emerged as the most highly prioritized factors affecting thermal comfort. When transitioning from theoretical importance to practical implementation, the hierarchy of effectiveness shifted toward physical, structural interventions and human factors. Horizontal overhangs, the effect of occupant behavior, and site orientation recorded the highest effectiveness ratings. These findings indicate that passive cooling in the Sudan Savannah climate is best achieved through concrete architectural elements—such as dedicated structural shading—and an active understanding of how occupants interact with their spatial environment, rather than relying solely on generalized natural ventilation or passive glazing. The study further established that site-level interventions and green infrastructure have considerable potential for improving environmental performance. Landscaping and the utilization of local materials were highly evaluated by respondents and were also observed to contribute significantly to passive cooling within the selected case studies. These approaches provide additional environmental benefits, including reduced urban heat island effects and improved visual quality of the built environment. The comparative analysis of Eko Pearl Towers, Bosco Verticale, One Central Park, and the World Trade Center Abuja demonstrated that successful passive design depends on the integration of multiple complementary strategies rather than reliance on a single intervention. All four projects utilized combinations of orientation, ventilation, shading systems, façade treatments, landscape integration, and environmentally responsive planning to improve thermal performance and occupant comfort. Overall, the study concludes that the adoption of targeted passive design strategies (prioritizing spatial quality, structural overhangs, and landscape integration) can significantly improve thermal comfort, reduce operational energy consumption, minimize dependence on mechanical cooling systems, and promote environmentally sustainable housing development in Yola and similar tropical regions.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

- a. **Prioritize structural horizontal overhangs and specific site orientation:** High-rise condominium buildings must be positioned to minimize prolonged exposure to direct solar radiation along east-west axes, utilizing fixed horizontal overhangs as the primary defense against solar heat gain.
- b. **Elevate fundamental indoor space quality and occupant education:** Design development must prioritize spatial configurations that naturally support comfort, while

developers should provide guidelines to occupants on how to optimally interact with operable passive systems (e.g., when to open windows or deploy secondary shading).

- c. **Integrate localized green infrastructure and landscaping:** Landscaped courtyards, podium gardens, and urban vegetation should be heavily incorporated at the site level to reduce surrounding ambient temperatures before heat reaches the building envelope.
- d. **Mandate the use of thermally efficient, local building materials:** Designers and developers should prioritize locally sourced materials with favorable thermal mass and insulation properties to improve building envelope performance efficiently and sustainably.
- e. **Strengthen the integration of climatic data into the design process:** Architects and planners should utilize local climatic information, including solar paths and wind patterns, to inform structural shading and orientation decisions.
- f. **Adopt digital building performance evaluation tools during project development:** Simulation software and environmental performance assessment tools should be utilized to predict thermal performance and optimize passive design strategies before construction.
- g. **Enhance professional awareness and capacity development:** Professional bodies, academic institutions, and government agencies should organize training programs focused on the practical effectiveness of passive design principles.
- h. **Review and strengthen building regulations relating to thermal performance:** Relevant regulatory authorities should incorporate clear provisions mandating passive environmental design strategies within building approval frameworks.

5.3 Implications for Sustainable Housing Development

The findings of this study have important implications for sustainable housing delivery in Nigeria. As urbanization continues to increase and high-rise residential developments become more common, there is a growing need to reduce energy demand while improving occupant well-being. The adoption of passive design strategies offers a practical and cost-effective approach to addressing thermal comfort challenges without increasing dependence on energy-intensive cooling systems. The successful implementation of passive environmental design measures can contribute to reduced greenhouse gas emissions, lower household energy expenditures, improved indoor environmental quality, and enhanced urban sustainability. Consequently, passive design should be regarded as a fundamental component of future high-rise residential development strategies in Yola, Adamawa State, and other regions with similar climatic conditions.

5.4 Limitation of the Study

This study was limited to the assessment of passive design strategies through professional perceptions and comparative case study analysis. The research did not include post-occupancy thermal measurements or detailed building performance simulations of existing high-rise condominium developments in Yola. Future studies may incorporate field-based thermal monitoring, computational simulations, and occupant satisfaction assessments to further validate the effectiveness of the identified passive design strategies under actual operating conditions.

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