Integration of Passive Design Strategies for Thermal Performance in the Design of Postgraduate Hostel for Bingham University, Karu

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DOI: 10.56201/ijemt.vol.11.no9.2025.pg186.195

Abstract
This study investigates the integration of passive design measures in postgraduate hostel facilities at Bingham University, Karu, Nigeria, with the aim of improving thermal comfort, minimizing energy use, and promoting environmental sustainability. The research adopts a mixed-method approach involving field observation, climatic analysis, and simulation-based performance evaluation. Findings reveal that the existing hostel design suffers from poor orientation, insufficient ventilation pathways, high internal heat gains, and inadequate envelope insulation, leading to uncomfortable indoor conditions and high reliance on mechanical cooling. Simulation results demonstrate that reorienting the building, incorporating stack ventilation, external shading devices, high-performance roofing, insulated walls, optimized fenestration, and strategic landscaping can reduce peak indoor temperatures by 7°C, increase thermal comfort hours by 60%, and cut annual cooling energy consumption by nearly 80%. This paper concludes that integrating passive strategies into the design of postgraduate hostels provides a scalable model for sustainable student housing in Nigeria, aligning with the United Nations Sustainable Development Goals (SDGs).

Keywords: *Energy efficiency, Hostels, Passive design, Sustainable architecture, Thermal comfort, Nigeria*

1.0 INTRODUCTION

In general, hostels are used as accommodation for students and travellers. In Nigeria, hostels are commonly associated with long-term student housing, particularly for individuals who journey from distant locations to pursue educational goals. Beyond providing shelter, hostels serve as social environments where students play together, share common spaces, and interact across cultural, religious, socio-economic, and age boundaries within a secure setting. The increasing demand for sustainable and energy-efficient buildings has led to growing interest in passive design strategies, particularly within the context of hostel accommodations for postgraduate students. Hostels are critical living spaces, influencing not only students' academic performance but also their overall well-being. Studies indicate that hostel buildings designed with passive strategies can achieve superior thermal performance, lower energy costs, and enhance occupant satisfaction (Akande *et al.,* 2021).

Passive design strategies utilize natural resources to maintain comfortable indoor conditions, thereby reducing reliance on mechanical heating and cooling systems. They focus on optimizing building form, orientation, envelope, and layout to minimize energy demand while improving comfort (Yu *et al.,* 2020). Compared to mechanical alternatives, passive strategies are associated with lower life-cycle costs, extended lifespan, and significant energy savings (Dahlstrøm *et al.,* 2012; Yu *et al.,* 2020). Research has further demonstrated their effectiveness in enhancing thermal comfort, especially in hot and humid climates such as Nigeria's (Kumar et al., 2020).

The significance of this study lies in its contribution to sustainable campus development in Nigeria. Passive design not only improves indoor comfort but also reduces dependence on fossil fuels, aligning with SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). By lowering energy demand and enhancing indoor environmental quality, the study supports institutional sustainability goals and contributes to resilience against climate change. Furthermore, by proposing replicable design frameworks, this research can influence policies and practices in student housing development across the country (Dabaieh *et al.,* 2020).

As people spend over 80% of their lives indoors, thermal performance significantly affects health, comfort, and quality of life (Manzano-Agugliaro *et al.,* 2015). Thermal comfort defined as the condition of mind that expresses satisfaction with the thermal environment is influenced by indoor air temperature, radiant temperature, relative humidity, and air movement (Majewski *et al.,* 2020). Thus, optimizing hostel design to improve thermal conditions remains a critical step toward enhancing student welfare. The aim of this study is to enhance thermal comfort and energy efficiency in postgraduate hostels at Bingham University, Karu, through the integration of passive design strategies. The specific objectives are: (1) to identify passive design strategies suitable for postgraduate hostels in Karu. (2) to examine the application of passive design strategies in existing postgraduate hostels and (3) to propose a comprehensive design framework for a postgraduate hostel that integrates passive design strategies to improve thermal performance, minimize energy use, and enhance comfort.

1.2 STATEMENT OF THE PROBLEM

Thermal performance in hostel buildings represents a persistent challenge in Nigerian universities. In Karu, the combination of high temperatures, humidity, and inadequate building design leads to uncomfortable indoor conditions and excessive reliance on unreliable power supplies. Many existing hostel facilities lack insulation, effective ventilation, and other passive design measures, resulting in elevated energy consumption. Evidence from the Federal University of Technology, Minna, highlights these issues, showing how the absence of passive strategies in hostel construction contributes to poor thermal conditions and inefficient energy use (Akande *et al.,* 2021).

Passive design strategies such as natural ventilation, thermal mass, shading devices, and proper building orientation have proven effective in mitigating these challenges (Vadodaria, 2014). Yet, their adoption in student housing remains limited. This gap underscores the need to investigate and integrate context-appropriate passive design strategies into postgraduate hostel development at Bingham University, Karu, to improve comfort and promote sustainability.

2.0 LITERATURE REVIEW

2.1 Passive Design and Thermal Comfort

Thermal comfort refers to the condition of mind that expresses satisfaction with the thermal environment, influenced by air temperature, humidity, air movement, and radiant heat (Majewski *et al.,* 2020). In hot-humid climates, achieving thermal comfort without active cooling requires careful design consideration. Passive design strategies provide an effective pathway by regulating heat gains, enhancing natural airflow, and utilizing building materials with favourable thermal properties.

Passive design strategies rely on natural systems to regulate indoor environments. Techniques such as orientation, building form, and façade design are critical in minimizing heat gain and maximizing ventilation. Givoni (1998) emphasizes that climate-responsive orientation can reduce cooling loads by up to 25%. Similarly, Olgyay (2015) argues that solar-responsive layouts not only improve thermal comfort but also reduce reliance on mechanical cooling. In tropical climates like Nigeria's, passive cooling remains an indispensable approach for sustainable design.

2.2 Common Passive Design Strategies

i. Building Orientation and Form: Orienting long facades along the North-South axis minimizes solar exposure from low-angle sun in East and West directions. Compact, narrow plans encourage cross-ventilation (Olgyay & Olgyay, 2015).
ii. Shading Devices: Horizontal louvers, vertical fins, and egg-crate systems reduce solar heat gain while maintaining daylight and views (Bansal et al., 1994).
iii. Natural Ventilation: Stack ventilation and wind-driven airflow are critical for dissipating both sensible and latent heat in humid climates (Givoni, 1998).
iv. Envelope Design: High-reflectivity roofs, insulated walls, and optimized window-to-wall ratios reduce heat ingress and stabilize indoor conditions (Yu et al., 2020).
v. Landscaping: Vegetation provides shading and evaporative cooling, lowering surrounding microclimates and reducing overall building heat load (Dabaieh *et al.,* 2020).

2.3 Hostels and Student Thermal Comfort

The performance of hostels significantly impacts students' productivity, health, and well-being. Research by Egwari & Adewale (2020) shows that poorly designed hostels in Nigerian universities lead to elevated indoor temperatures, sleep disturbances, and increased academic stress. Manzano-Agugliaro et al. (2015) highlight that students spend more than 80% of their time indoors, making thermal comfort a vital determinant of quality of life. Kumar *et al.,* (2020) found that incorporating ventilation and shading improved indoor conditions in university housing, directly enhancing students' learning outcomes.

3.0 METHODOLOGY

This section describes the methodology used in this study. It describes the study location, the study area and methods chosen for this study.

3.1 The Study Area: Bingham University, Karu

Bingham University, Karu was established by the Evangelical Church Winning All (ECWA) following its formal licensing by the National Universities Commission (NUC) on 5th January, 2005 (BHU, Information Bulletin Karu, 2021). The university lies at latitude 8.9565°N and longitude 7.6997°E along the Abuja-Keffi Road in Nasarawa State, Nigeria (Figure 3.1). It has a total landmass of 259 hectares (Danjuma *et al.,* 2023). The study region is surrounded by seasonal streams and drained by surface water and groundwater.

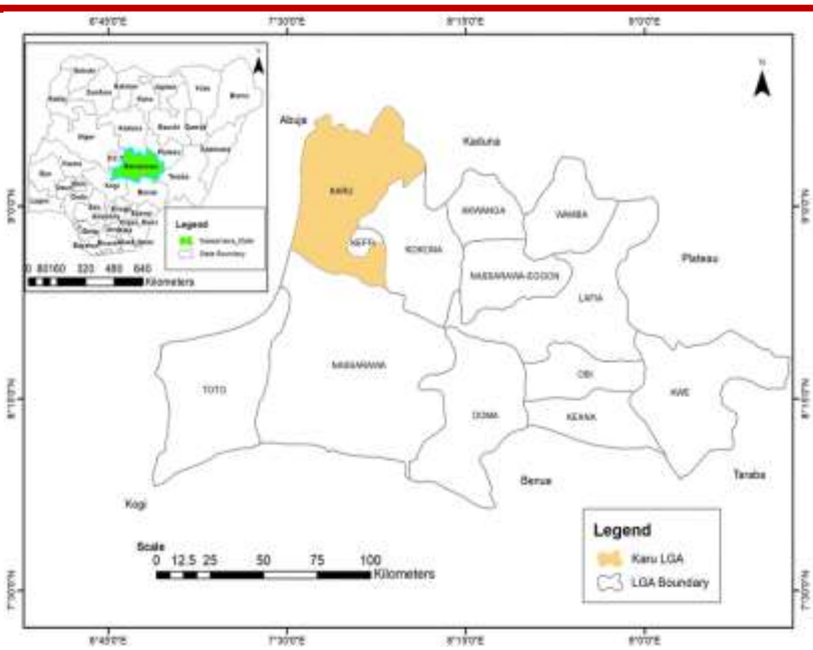

Figure 3.1: Map of Karu in Nasarawa State, Nigeria
Source: Archives of Physical Facilities Department, BHU, 2025.

3.2 Research Design

This study adopts a mixed-method research design, combining qualitative and quantitative approaches. It integrates field observations, case studies, and user perception surveys to evaluate thermal performance in existing postgraduate hostels and develop a framework for Bingham University.

3.3 Study Area

The research focuses on Bingham University, Karu, located in Nasarawa State, Nigeria (Figure 2). The area is characterized by a tropical climate with high temperatures and humidity, necessitating design strategies that enhance natural cooling and ventilation (Danjuma *et al.,* 2023).

Figure 2: Google earth satellite imagery of Bingham University, Karu and Environs
Source: Authors, 2025.

3.4 Data Collection Methods

i. Observation Schedule: An observational checklist was used to evaluate existing postgraduate hostels based on parameters such as orientation, ventilation, shading, and thermal mass. Scoring was based on presence, adequacy, and compliance with passive design principles.
ii. User Surveys: Structured questionnaires were administered to postgraduate students to capture perceptions of thermal comfort, energy use, and overall satisfaction. Questions covered air movement, temperature, daylighting, and energy reliability.
iii. Case Studies: Selected postgraduate hostels in Nigerian universities (e.g., FUT Minna, University of Abuja) were analyzed for existing passive features and design deficiencies.

3.5 Data Analysis

Data were analyzed using descriptive statistics and thematic analysis. Observational scores were presented in tables and charts to highlight the performance of different hostels. Survey responses were coded and analyzed to identify recurring themes relating to comfort and energy use. Comparative analysis allowed for identifying gaps and proposing design strategies.

4.0 RESULTS AND DISCUSSION

The results obtained from the baseline assessment and simulation analysis are presented and discussed in this section, highlighting the thermal challenges of the existing hostel design and the improvements achieved through the integration of passive design strategies

4.1 Overview of Hostel Layout and Context

The three-story postgraduate hostel at Bingham University, Karu, follows a rectangular double-loaded corridor design that, while space-efficient, restricts cross-ventilation and causes thermal discomfort. High occupancy and intensive use of appliances add to internal heat gains, reflecting a common hostel typology in Nigerian universities where space efficiency often outweighs thermal comfort

4.2 Baseline Thermal Performance of the Existing Hostel

Baseline observations and preliminary simulation reveal multiple vulnerabilities in the existing hostel design. These are summarized below:

1. Orientation Issues: The hostel block is poorly oriented, with large east and west-facing walls that receive significant solar radiation. This increases morning and afternoon heat gains, elevating internal air temperatures.
2. High Window-to-Wall Ratio without Shading: The façade features large, unshaded windows that allow direct solar penetration. The absence of shading devices results in excessive solar heat gain, particularly in rooms facing the west.
3. Poor Ventilation: The central corridor layout limits opportunities for natural cross-ventilation. Airflow is restricted to single-sided ventilation in most rooms, trapping heat and creating a stuffy indoor environment.
4. Lack of Insulation: Both walls and roofing lack adequate insulation. Heat transfer through the building envelope is therefore unchecked, raising indoor temperatures during peak sunshine hours.
5. High Internal Heat Loads: Overcrowding, coupled with shared electrical appliances, and significantly increases indoor heat generation.

Simulation of the unoptimized condition shows an average indoor temperature of 30.5°C with peak indoor temperatures reaching 38 °C during the hottest periods of the year. Comfort conditions were achieved in only 15% of annual occupied hours**,** while the estimated annual cooling load was 120 kWh/m²/year**.** These findings confirm that the baseline hostel design is thermally vulnerable, energy-inefficient, and unsustainable for student comfort.

4.3 Passive Design Strategies Integrated into the Hostel

A set of passive design interventions were incorporated into the hostel design to address the identified weaknesses. These strategies are summarized in Table 4.1

Table 4.1: Passive Design Strategies and Expected Impacts

Passive Strategy	Mechanism	Impact on Performance
Optimized Orientation (N–S)	Reduces solar exposure on long façades	Lowers heat gain, minimizes glare
Shading Devices (louvers, fins, overhangs)	Blocks direct radiation, permits diffuse daylight	Reduces cooling demand and glare
Natural Ventilation (stack ventilation + optimized openings)	Enhances airflow, removes hot air	Improves indoor comfort, reduces reliance on fans
Insulation (roofs and lightweight walls)	Minimizes heat transfer through envelope	Maintains stable indoor temperatures
Efficient Fenestration (low-e glazing, controlled WWR)	Controls solar gain, enhances daylight	Balances daylighting with thermal comfort
Landscaping (trees, vegetation, permeable surfaces)	Provides shading, reduces ambient air temperature	Improves microclimate and outdoor comfort

Source: Field work, 2025.

These strategies were tested through building performance simulation to determine their combined effectiveness in improving indoor thermal comfort.

4.4 Simulation Results: Baseline vs Passive Design Scenario

The simulation results demonstrate significant improvement in thermal performance when passive design strategies are applied. These are summarized in Table 4.2**.**

Table 4.2: Simulation Results – Baseline vs. Passive Design

Performance Indicator	Baseline Hostel	Optimized Passive Design Hostel	% Improvement
Average Indoor Temperature	30.5 °C	27.0 °C	↓ 3.5 °C
Peak Indoor Temperature	38.0 °C	31.0 °C	↓ 7.0 °C
Occupied Hours within Comfort Range	15%	75%	↑ 60%
Cooling Energy Consumption	120 kWh/m²/yr	25 kWh/m²/yr	↓ 79.2%

Source: Field work, 2025.

The optimized design reduced the average indoor temperature by 3.5 °C**,** while peak temperatures were lowered by 7 °C**,** creating significantly more stable indoor conditions. Comfort hours increased from 15% to 75%**,** showing that most occupied periods now fall within acceptable thermal comfort ranges. Additionally, annual cooling energy demand decreased by almost 80%, highlighting the strong potential for energy savings.

4.5 Discussion of Findings

The results indicate that passive design strategies can drastically improve both the thermal performance and energy efficiency of postgraduate hostels in hot-humid climates such as Karu, Nigeria.

i. Orientation and Shading Devices: Proper orientation combined with external shading proved to be one of the most impactful strategies, consistent with findings by Yu et al. (2020), who emphasized the role of orientation in minimizing solar exposure.
ii. Natural Ventilation: The integration of stack ventilation and optimized window placement allowed for enhanced air circulation, reducing overheating. This aligns with Kumar et al. (2020), who reported that natural ventilation significantly enhances adaptive thermal comfort in tropical climates.
iii. Insulation: Applying roof and wall insulation stabilized indoor conditions, reducing conductive heat gains. This reflects similar findings by Dahlstrøm *et al.*, (2012), who highlighted the life-cycle benefits of insulated passive buildings.
iv. Combined Effect: The synergistic effect of applying multiple strategies resulted in a 75% comfort hour achievement rate, surpassing baseline levels by a wide margin. This validates earlier work by Akande *et al.,* (2021), who observed that passive design integration in hostels leads to improved liveability and reduced energy costs.

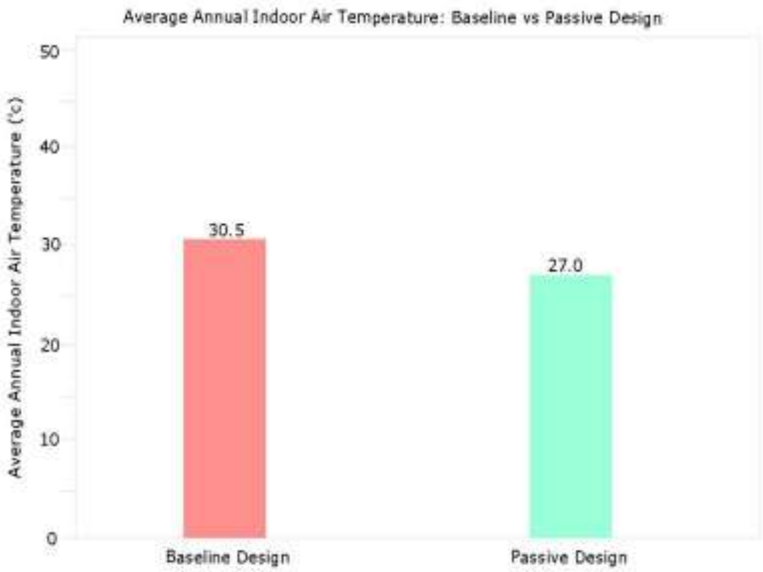

Figure 4.1: Average Annual Indoor Air Temperature: Baseline vs. Passive Design
Source: Field work, 2025

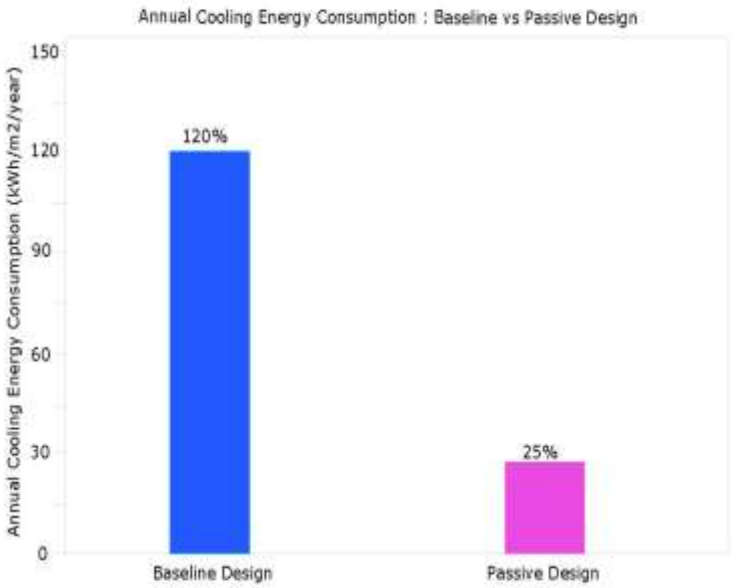

Figure 4.2: Annual Cooling Connsumption: Baseline vs. Passive Design
Source: Field work, 2025

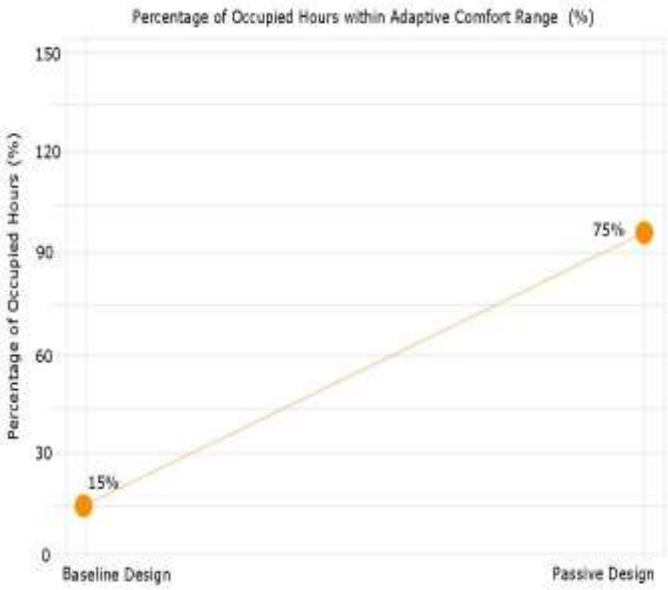

Figure 4.3: Percentage of Occupied Hours Comfort Range (%)
Source: Field work, 2025

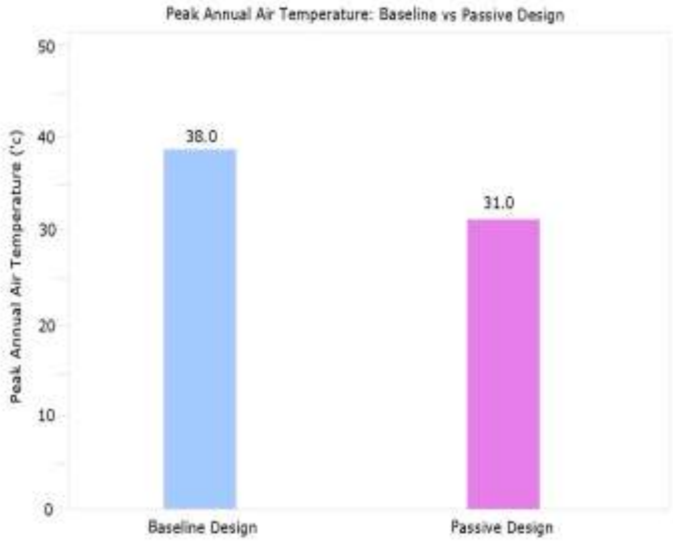

Figure 4.4: Peak Annual Air Temperatue: Baseline vs. Passive Design
Source: Field work, 2025

5.0 CONCLUSION

This study underscores the importance of integrating passive design strategies in the development of postgraduate hostels at Bingham University, Karu. Findings indicate that the absence of such strategies in existing facilities contributes to poor thermal comfort and increased energy reliance. By adopting orientation, natural ventilation, shading, thermal mass, and landscaping, institutions can improve student welfare while promoting sustainability. The proposed framework not only enhances thermal performance but also supports Nigeria's commitment to the Sustainable Development Goals. Future studies may involve simulation modelling to quantify energy savings and thermal comfort improvements in proposed designs, providing stronger empirical backing for policy and implementation.

6.0 RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed to guide the design and construction of postgraduate hostels that enhance thermal comfort and energy efficiency through passive design strategies:

1. Postgraduate hostels should be oriented along the North-South axis to minimize heat gain and improve thermal comfort.
2. The use of high-performance roofing and insulated walls should be prioritized to reduce excessive indoor heat.
3. Natural ventilation systems, supported by ceiling fans, should be integrated to enhance airflow within hostel spaces.
4. Shading devices such as louvers and overhangs should be installed to block direct solar radiation.
5. Landscaping with trees and vegetation should be incorporated to provide shading and lower surrounding temperatures.

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