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Evaluating the Effectiveness of Bioclimatic Design Strategies in Warm-Humid Institutional Buildings

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Abstract: *Warm-humid climatic zones present enduring challenges to achieving indoor thermal comfort in naturally ventilated institutional buildings. Despite growing global interest in bioclimatic architecture, empirical assessments of passive design effectiveness in public university buildings across tropical Sub-Saharan Africa remain sparse. This study evaluates the effectiveness of five core bioclimatic design strategies (building orientation and layout, shading devices, opening and ventilation systems, landscaping, and internal courtyards) in 62 public university buildings constructed between 2012 and 2023 across six state capitals in Southwest Nigeria. A mixed-methods approach integrated objective bioclimatic audits, Evans Comfort Scale and Mahoney Table analyses, indoor environmental measurements using a calibrated Kestrel 4500 Weather Meter, and subjective post-occupancy evaluations from 374 validated respondents. Findings reveal significant deficiencies in the implementation of all five strategy categories. Opening and ventilation systems registered the highest importance index (II = 4.17) among occupants, followed by landscaping (II = 3.67), courtyards (II = 3.34), orientation/layout (II = 3.21), and shading devices (II = 3.20). Multivariable ordinal logistic regression identified perceived indoor temperature ($\beta = 1.58$; OR = 4.86; $p < .001$) and air velocity ($\beta = 0.94$; OR = 2.56; $p = .002$) as the strongest physiological predictors of thermal comfort satisfaction. Building openings exerted the greatest design-based influence on comfort outcomes ($\beta = 1.42$; OR = 4.14; $p < .001$). Approximately 69.8% of respondents reported thermal discomfort, with afternoon conditions (12:00–18:00 h) rated most uncomfortable by 59.4% of occupants. The study establishes location-specific thermal comfort indices and bioclimatic design benchmarks for six Nigerian cities, contributing empirical data toward the revision of the Nigeria Building Energy Efficiency Code (N-BEEC) and advocating for the integration of adaptive passive design guidelines in institutional building policy.*

Keywords: bioclimatic design, thermal comfort, passive cooling, warm-humid climate, institutional buildings, Nigeria, post-occupancy evaluation, natural ventilation, shading devices, courtyard design

INTRODUCTION

The building sector is responsible for approximately 36% of global final energy consumption and nearly 39% of energy-related carbon dioxide emissions (International Energy Agency [IEA], 2023). Within this sector, institutional buildings including universities, hospitals, and governmental facilities represent a disproportionately energy-intensive typology, often characterized by high occupancy densities, extended operational hours, and growing demands for indoor environmental quality (Al-

Tamimi & Fadzil, 2011; Nguyen et al., 2012). In tropical and warm-humid climates, where ambient temperatures frequently exceed thermal comfort thresholds, mechanical air conditioning has become the default response, intensifying energy demand and greenhouse gas emissions (Hyde, 2000; Yusuf, 2020).

In Nigeria, the built environment faces a dual crisis: endemic indoor thermal discomfort and unreliable electricity supply, with only approximately 55% of the population having consistent grid access and average supply hours of fewer than 12 hours per day in urban areas (World Bank, 2022; Nigerian Energy Support Programme [NESP], 2021). Public university buildings, central to knowledge production, sustainability modeling, and policy demonstration (Mohammadalizadehkorde & Weaver, 2018), are disproportionately impacted. Buildings not designed in accordance with bioclimatic principles generate excessive internal heat loads, reduce occupant productivity, impair academic performance, and accelerate reliance on diesel-powered mechanical cooling systems (Chung et al., 2018; Ezema et al., 2016).

Bioclimatic architecture which is also referred to as passive design, climate-responsive design, or low-energy architecture offers a scientifically grounded and economically viable alternative. Rooted in the foundational work of Olgyay (1963) and expanded by Givoni (1976) and Evans (2007), bioclimatic design leverages site-specific environmental forces such as solar radiation, prevailing winds, thermal mass, and vegetation to regulate indoor microclimates without mechanical intervention (Szokolay, 2008; Kamal, 2012). Five design strategies have been consistently identified in the literature as critical to passive thermal performance in warm-humid institutional settings: (i) building orientation and layout, (ii) shading devices, (iii) opening and ventilation systems, (iv) landscaping and vegetation integration, and (v) internal courtyard design (Ogunsote et al., 2012; SKAT, 2003; Jamaludin et al., 2014).

Despite their theoretical foundations and empirical validation in residential and commercial typologies, these strategies remain inconsistently applied and systematically under-evaluated in Sub-Saharan African institutional buildings (Okoye et al., 2020; Adegbie, 2021). The majority of thermal comfort research in Nigeria has focused on residential buildings (Adunola, 2011; Yusuf, 2020), neglecting public institutions that are governed by different occupancy patterns, procurement processes, and regulatory frameworks. Furthermore, global comfort standards such as ASHRAE Standard 55 (ASHRAE, 2020) and ISO 7730 developed predominantly for temperate, mechanically conditioned environments have limited applicability in warm-humid, naturally ventilated contexts where adaptive comfort mechanisms predominate (de Dear & Brager, 2002; Nicol & Humphreys, 2010).

Critically, Nigeria lacks localized thermal comfort benchmarks and region-specific bioclimatic design guidelines (Ogunsote & Prucnal-Ogunsote, 2003). The Nigeria Building Energy Efficiency Code (N-BEEC), developed in 2016, provides only broad prescriptions and has experienced limited implementation in institutional building procurement (NESP, 2021). This regulatory void, combined with the absence of post-occupancy evaluation (POE) data, creates a significant design-policy gap that perpetuates thermally inadequate university buildings.

This study addresses these deficiencies by conducting a comprehensive empirical assessment of bioclimatic design strategy effectiveness in 62 public university buildings across Southwest Nigeria. The investigation is structured around five focal design variables aligned with established passive cooling frameworks, and integrates both objective environmental measurements and subjective occupant perceptions. The specific objectives are to: (1) establish location-specific thermal comfort indices using the Evans Comfort Scale and Mahoney Tables; (2) conduct systematic bioclimatic audits of university buildings; (3) assess occupant thermal comfort perceptions; (4) determine the relative influence of each bioclimatic strategy on thermal comfort satisfaction; and (5) generate evidence-based design guidelines for warm-humid institutional buildings.

The study contributes to international literature by producing a large-scale, multi-campus empirical dataset from a globally underrepresented warm-humid context, and by advancing the development of adaptive passive design frameworks suitable for low- and middle-income tropical countries. The findings offer practical insights for architects, policymakers, and facility managers seeking to reduce energy dependence and improve indoor environmental quality in the rapidly urbanizing institutional building sector of Sub-Saharan Africa.

LITERATURE REVIEW

Bioclimatic Design in Warm-Humid Climates

Bioclimatic design refers to an architectural approach that aligns the built form with local climatic conditions to optimize indoor comfort through passive means- primarily solar control, natural ventilation, thermal mass, and evaporative cooling while minimizing reliance on energy-intensive mechanical systems (Hyde, 2000; Szokolay, 2008). In warm-humid climates, characterized by high ambient temperatures (typically 28–35°C), elevated relative humidity (70–100%), intense solar radiation, and minimal diurnal temperature variation, passive cooling strategies are not merely advantageous but architecturally essential (SKAT, 2003; Ogunsote et al., 2012).

Victor Olgyay’s Bioclimatic Chart (1963) established the conceptual foundation for matching building design responses to climatic zones, emphasizing orientation, fenestration, shading, and thermal mass as primary design levers. Givoni (1976) extended this framework to include the Building Bioclimatic Chart (BBCC), which identified passive cooling mechanisms including natural ventilation, evaporative cooling, and thermal mass with night flushing applicable in hot-humid environments. Contemporary bioclimatic tools, including the Evans Comfort Scale (Evans 1980; Evans, 2007), Mahoney Tables (Mahoney, 1976), and simulation platforms such as DesignBuilder and ENVI-met, have formalized these principles into quantitative diagnostic and prescriptive instruments validated for tropical climates (Ogunsote and., 2003; Bodach et al., 2014).

In warm-humid regions specifically, natural ventilation through optimized openings, combined with external shading and courtyard-mediated airflow, has demonstrated reductions in indoor operative temperatures of 3–6°C and mechanical cooling load reductions of 30–60% in institutional building typologies across Southeast Asia and West Africa (Jamaludin et al., 2014; Ezema et al., 2016; Fotakis et al., 2014). Landscaping integrating strategic vegetation particularly trees with broad canopies and evergreen hedges can reduce ambient microclimate temperatures by 1–5°C through evapotranspiration and solar shading (Kamal, 2012; Akbari & Kurn, 1997). Courtyard configurations, when properly proportioned (length:width:height = 1:2:1.4 with east-west orientation), facilitate stack-effect ventilation that reduces indoor temperatures during peak heat periods (Mohammed & Alibaba, 2018; Heidari, 2000).

Despite compelling evidence for their efficacy, the practical implementation of bioclimatic strategies in Nigerian institutional buildings remains constrained by inadequate professional training, weak regulatory enforcement, budgetary pressures favoring short-term cost minimization, and a persistent preference for aesthetics-driven, climate-agnostic design borrowed from temperate architectural models (Geissler et al., 2018; Yusuf, 2020; Okoye et al., 2020). Recent studies further confirm that existing passive installations in Nigerian public buildings frequently underperform due to poor maintenance, user-mediated obstruction of ventilation pathways, and mismatch between design intent and local microclimatic conditions (Adegbie, 2021; Kweku et al., 2018).

Thermal Comfort in Naturally Ventilated Institutional Buildings

Thermal comfort is defined by ASHRAE Standard 55 (2020) as “the condition of mind that expresses satisfaction with the thermal environment,” and is determined by the interaction of environmental parameters such as air temperature, mean radiant temperature, air velocity, and relative humidity with personal factors including metabolic rate and clothing insulation (Fanger, 1970; Szokolay, 2008). The Predicted Mean Vote (PMV)/Predicted Percentage of Dissatisfied (PPD) model, the dominant framework in international standards, was developed under controlled, steady-state conditions in mechanically conditioned spaces and has been extensively critiqued for its limited applicability in naturally ventilated tropical environments where conditions fluctuate dynamically (de Dear & Brager, 2002; Nicol & Humphreys, 2010).

The Adaptive Thermal Comfort Model (ATM), incorporated into ASHRAE 55 for naturally ventilated buildings, posits that occupants in free-running spaces can maintain thermal satisfaction across wider temperature ranges often 25–32°C in tropical regions through behavioral adaptation (window operation, clothing adjustment, positional changes) and psychological acclimatization (Brager & de Dear, 2001; Nicol & Humphreys, 2002). This model has been validated in field studies across Southeast Asia, India, and West Africa, where neutral temperatures ranging from 26.7–32°C have been recorded, significantly exceeding ISO 7730 thresholds (Jamaludin et al., 2014; Heidari, 2000; Ogunsote & Prucnal-Ogunsote, 2003). In Nigerian university settings specifically, Adunola (2011) found that occupants demonstrated meaningful adaptive comfort strategies, yet remained frequently dissatisfied due to inadequate passive design provision, particularly poor ventilation and insufficient shading.

In educational buildings, thermal discomfort is not merely an environmental inconvenience but a pedagogical determinant. Research consistently demonstrates that indoor temperatures exceeding 28°C reduce cognitive performance, increase absenteeism, and diminish academic productivity (Chung et al., 2018; Haverinen-Shaughnessy & Shaughnessy, 2015). University lecture halls, which may accommodate 50–500 occupants with correspondingly high metabolic heat loads, are particularly vulnerable to thermal overheating in inadequately ventilated structures (Jamaludin et al., 2014; Fotakis et al., 2014).

Field-based comfort studies from comparable warm-humid contexts confirm that perceived air velocity and temperature are the dominant predictors of occupant thermal satisfaction in naturally ventilated institutional spaces (Ogbonna & Harris, 2008; Ayinla & Odetoye, 2015; Ayinla 2018). Ogunsote and Prucnal-Ogunsote (2003) validated the combined application of the Evans Comfort Scale and Mahoney Tables as optimal diagnostic tools for Nigerian climatic contexts, establishing location-specific comfort temperature ranges and passive design prescriptions that account for seasonal humidity variations. These tools remain the most contextually appropriate instruments for warm-humid institutional building assessment in Nigeria.

The Five Focal Bioclimatic Strategies: State of Evidence

Building orientation and layout constitute foundational passive design decisions that determine solar exposure, wind exposure, and airflow potential across a building's lifespan (Almansuri, 2010; Givoni, 1998). For warm-humid climates, the Mahoney Tables consistently recommend east-west axis elongation for the main building mass, minimizing east and west façade solar exposure while maximizing the north-south wall area for cross-ventilation openings. Lawal (2008) demonstrated in Nigerian office buildings that east-west orientation reduced indoor temperature by up to 2.5°C compared to north-south-oriented counterparts. Open settlement spacing with a minimum building separation of five times average building height further enhances airflow penetration and reduces inter-building heat accumulation (Ayinla et al., 2013; Givoni, 1998).

Shading devices represent the first line of defense against solar heat gain, which is the dominant driver of indoor temperature elevation in warm-humid environments (Kumar et al., 2005; Kamal, 2012). Properly designed overhangs, vertical fins, louvers, and egg-crate configurations with minimum shading angles of 30° can reduce indoor temperatures by 2.5–6.8°C (Kumar et al., 2005). Ahsan and Svane (2010) demonstrated energy savings of 6–14% attributable to optimized external shading devices across different façade orientations. Contemporary research in West Africa confirms that shading provision is among the most cost-effective passive retrofits available for existing institutional buildings (Ezema et al., 2016; Adebisi et al., 2018).

Natural ventilation through openings is the most extensively studied passive strategy in warm-humid climates and has been identified as the critical determinant of indoor thermal comfort in free-running buildings (Walker, 2010; Lawal, 2008). The Mahoney Tables prescribe large openings (40–80% of north and south wall area) for maximum cross-ventilation in high-humidity contexts, with single-banked room configurations to maintain through-air movement. Stack ventilation, facilitated by high-level openings and atriums, complements cross-ventilation during periods of low wind speed (Cofaigh et al., 1996). Jamaludin et al. (2014) documented air velocity improvements of 0.3–0.8 m/s in Malaysian university lecture halls following ventilation optimization retrofits, with corresponding improvements in occupant comfort ratings of 18–27%.

Landscaping and vegetation integration exert compound passive cooling effects through solar shading, evapotranspiration, wind deflection, and psychological well-being enhancement (Kamal, 2012;

Ogunsote et al., 2012). Strategic tree planting; particularly evergreen species on west and southwest facades and deciduous trees on south facades can reduce ambient microclimate temperatures by 2–5°C (Akbari & Kurn, 1997; SKAT, 1993). In institutional campuses, Huang (1987) demonstrated that integrated landscape design reduced peak cooling loads by up to 25% compared to unplanted control sites. Despite its demonstrated efficacy, landscape integration remains among the least systematically implemented bioclimatic strategies in Nigerian university buildings (Ogunsote et al., 2012; Adebisi et al., 2018).

Internal courtyards represent a historically validated and climatically appropriate passive design typology for warm-humid environments, providing sheltered microclimate zones that promote stack-effect ventilation, reduce solar gain on adjacent room surfaces, and enable psychological connection to outdoor environments (Heidari, 2000; Muhaisen, 2006). Mohammed and Alibaba (2018) established that rectangular courtyard configurations with length-to-width-to-height ratios of 1:2:1.4, oriented along the east-west axis, optimize both shading effectiveness and airflow promotion. Contemporary university campuses in warm-humid Asia and the Middle East increasingly incorporate courtyard-based building configurations to meet thermal comfort targets without mechanical cooling (Muhaisen, 2006; Albadra, 2016).

Research Gaps

Despite extensive theoretical and some empirical literature on individual bioclimatic strategies, three critical gaps remain unaddressed in the West African institutional building context. First, there is an absence of multi-campus, multi-city empirical assessments that integrate objective environmental measurements with subjective occupant perceptions and systematic design audits. Second, the relative effectiveness of the five core bioclimatic strategies in predicting occupant thermal comfort satisfaction has not been quantified in Nigerian institutional buildings using regression-based modeling. Third, location-specific thermal comfort indices and prescriptive design guidelines grounded in post-occupancy evaluation data do not currently exist for Southwest Nigeria’s six state capitals, despite their distinct microclimatic profiles. This study directly addresses all three gaps.

METHODOLOGY

Research Design

This study adopted a convergent parallel mixed-methods design (Creswell & Plano Clark, 2018), integrating objective bioclimatic assessments with subjective post-occupancy evaluations (POEs) to produce a holistic, triangulated understanding of passive design effectiveness in warm-humid institutional buildings. The concurrent collection and analysis of quantitative environmental data, structured observational assessments, and occupant perception surveys ensured methodological rigor and inter-method validation.

Study Area and Case Selection

The study was situated in Southwest Nigeria, a geopolitical region comprising six states (Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti) characterized by a warm-humid tropical climate with annual mean temperatures between 24°C and 33°C, relative humidity consistently exceeding 70%, and a bimodal rainfall pattern (Nigerian Meteorological Agency [NiMet], 2025). The region hosts the highest concentration of public universities in Nigeria, making it a representative context for evaluating institutional bioclimatic design.

One public university was selected from the capital city of each state using a combination of purposive and simple random sampling (balloting), yielding a total of six institutions: Osun State University (UNIOSUN, Osogbo); Federal University of Technology Akure (FUTA, Akure); Ekiti State University (EKSU, Ado-Ekiti); University of Ibadan (UI, Ibadan); Federal University of Agriculture Abeokuta (FUNAAB, Abeokuta); and Lagos State University of Science and Technology (LASUSTECH, Lagos). Within each institution, all buildings designed, commissioned, and continuously occupied between 2012 and 2023 were identified through physical planning departments and reconnaissance surveys. This yielded a census of 62 buildings across the six campuses.

Bioclimatic Audit

A systematic bioclimatic audit was conducted on all 62 buildings. Structured observation schedules assessed ten architectural parameters across five strategy domains: (i) building orientation and layout (principal axis orientation, room configuration, inter-building spacing); (ii) shading devices (overhang depth, shading angle, fin type, coverage adequacy); (iii) opening and ventilation systems (window-to-wall ratio on N/S façades, openability, cross-ventilation provision, stack ventilation elements); (iv) landscape integration (tree species, placement relative to critical façades, coverage density); and (v) courtyard configuration (plan shape, dimensional ratios, orientation, shading provision). Each parameter was scored using a weighted bioclimatic compliance index derived from Mahoney Table prescriptions and established tropical design benchmarks (Ogunsote et al., 2003; Adebisi et al., 2018). Building scores were normalized and compared across institutions to identify implementation patterns.

Thermal Comfort Index Determination

Thermal comfort indices and passive design prescriptions for each state capital were determined through a hybrid analytical framework combining the Evans Comfort Scale and Mahoney Tables. Five years of monthly climatic data (2016–2023) per city comprising maximum and minimum air temperature, morning and afternoon relative humidity, and rainfall were obtained from NiMet stations at each state capital. The Evans Comfort Scale classified each month’s thermal stress using mean maximum temperature paired with minimum afternoon humidity (for daytime conditions) and mean minimum temperature paired with maximum morning humidity (for nighttime conditions), producing a five-level stress rating from “very cold” (−−) to “very hot” (++). Mahoney Tables were subsequently applied to translate climatic profiles into location-specific prescriptive design recommendations spanning layout, spacing, air movement provision, opening sizes, wall and roof construction, and rain protection.

Environmental Measurements

Indoor environmental conditions were measured using a calibrated Kestrel 4500 Pocket Weather and Environmental Meter, recording air temperature (°C), relative humidity (%), and air velocity (m/s) at 0.6 m above floor level in representative occupied zones of each building. Measurements were collected during the dry season period from December to March, identified by NiMet (2025), Ayinla (2018), and Ogunsote & Prucnal-Ogunsote, (2003) as the highest thermal stress period in Southwest Nigeria. Three measurements per space were taken at 09:00 h, 13:00 h, and 16:00 h to capture morning, peak afternoon, and late afternoon conditions. Indoor readings were benchmarked against Evans Comfort Scale thresholds to classify each space's thermal performance.

Post-Occupancy Evaluation

A structured questionnaire was administered to adult building users with a minimum occupancy tenure of two years (Gou et al., 2012) using incidental sampling at points of egress and common areas. The instrument comprised four sections: (i) socio-demographic characteristics; (ii) thermal comfort sensation ratings on a five-point Likert scale (1 = very cold to 5 = very hot); (iii) perceptions of indoor air temperature and air movement adequacy; and (iv) importance ratings for each of the five bioclimatic design strategies on a five-point scale. Of 496 questionnaires administered, 374 met the two-year occupancy criterion and were validated for analysis.

Data Analysis

Descriptive statistics (frequencies, means, standard deviations) characterized thermal comfort perceptions and bioclimatic strategy importance ratings. Importance Index (II) was calculated as $II = \Sigma(f \times s) / (N \times n)$, where f is response frequency, s is scale value, N is total responses, and n is the highest scale value. Multivariable ordinal logistic regression was employed to identify predictors of thermal comfort satisfaction, with thermal comfort rating as the dependent variable and perceived indoor temperature, perceived air velocity, and five bioclimatic strategy perception scores as independent variables. Proportional odds assumptions were verified using the Brant test. Statistical analyses were performed in SPSS version 27.0, with significance thresholds set at $p < .05$.

RESULTS

Thermal Comfort Indices for Southwest Nigeria

Table 1 presents the Evans Comfort Scale thermal stress classifications for the six study cities. Daytime conditions across all locations were predominantly hot (+) to very hot (++) from November through April during the dry season, with mean maximum temperatures ranging from 34.1°C (Ado-Ekiti) to 37.2°C (Abeokuta). Abeokuta exhibited the most severe thermal stress profile, recording very hot (++) daytime classifications for eight consecutive months and the highest recorded mean maximum temperature of 37.2°C in February. Lagos, as a coastal city with higher ambient humidity, demonstrated moderated thermal stress, achieving comfortable (0) classification in July–August. All six cities recorded predominantly cold (−) to comfortable (0) nighttime conditions, indicating significant diurnal temperature variation that creates favorable conditions for night ventilation strategies.

Table 1. Evans Comfort Scale Daytime Thermal Stress Summary for Six Southwest Nigerian Cities (2016–2023)

City	Jan–Mar	Apr–May	Jun–Sep	Oct–Nov	Dec	Peak Temp (°C)
Ibadan	++ / ++	+ / +	0 / +	+ / +	++	36.0
Akure	++ / +	+ / +	0 / +	+ / +	+	35.3
Ado-Ekiti	++ / +	+ / +	0 / +	+ / +	+	35.1
Osogbo	++ / +	+ / +	0 / 0	+ / +	+	35.9
Abeokuta	++	++	+	++	++	37.2
Lagos	++	+ / +	0 / +	+ / +	+	34.5

Note: ++ = Very Hot; + = Hot; 0 = Comfortable; − = Cold; −− = Very Cold. Source: Authors' analysis based on NiMet (2025) data.

Mahoney Table analyses produced consistent prescriptive recommendations across all six cities (Table 2), including east-west building axis orientation, open spacing for breeze penetration, single-banked room configurations with permanent air movement provision, medium-to-large openings (20–80% of N/S wall area), and light to heavy insulated roofs. Lagos, as the most humid city (annual mean RH > 77%), uniquely required large openings (40–80% of N/S walls) and Abeokuta was the only city without rain protection requirements for all months. These findings establish the first comprehensive set of empirically derived, location-specific bioclimatic design prescriptions for all six Southwest Nigerian state capitals.

Bioclimatic Audit Findings

The bioclimatic audit of 62 buildings across six universities revealed significant and consistent deficiencies in the implementation of all five focal design strategies (Table 2). Natural ventilation through openings was the most widely implemented strategy, present in 100% of buildings, though window-to-wall ratios on critical north and south façades frequently fell below the 40% Mahoney threshold, averaging 22.4% across the sample. The University of Ibadan demonstrated the strongest overall bioclimatic compliance, with comparatively better cross-ventilation provision, shading integration, and courtyard utilization. Lagos State University of Science and Technology (LASUSTECH) exhibited the weakest implementation, with minimal shading, no courtyards, and largely ornamental landscaping.

Shading devices were present in 71.0% of buildings but were assessed as adequately proportioned (shading angle ≥ 30°) in only 38.7% of cases. Horizontal overhangs dominated, with vertical fins present in only 12.9% of buildings, despite the predominance of east-west façades requiring vertical shading protection. Internal courtyards were incorporated in 29.0% of buildings, with only 38.9% of existing courtyards meeting recommended dimensional ratios. Landscape integration was present in all campuses but was assessed as effective (with evergreen coverage on critical west façades) in only

19.4% of buildings. Building orientation aligned with the recommended east-west axis in 64.5% of buildings; however, inter-building spacing met the minimum five-height separation criterion in only 27.4% of cases.

Occupant Thermal Comfort Perceptions

Of 374 validated respondents, 47.1% perceived indoor air temperatures as hot and 22.7% as very hot, yielding a combined thermal discomfort prevalence of 69.8%. Only 19.5% of respondents rated indoor conditions as comfortable, with 7.2% and 1.1% rating conditions as cold and very cold, respectively. Afternoon conditions (12:00–18:00 h) were identified as the most thermally uncomfortable period by 59.4% of respondents, followed by late morning (09:00–12:00 h) at 23.8%. Perceived indoor air movement was rated as poor or very poor by 50.0% of respondents (35.6% poor; 14.4% very poor), indicating widespread ventilation inadequacy. Heavy mechanical cooling system usage was reported by 78.6% of respondents, despite the substantial operational cost and reliability constraints these impose in the Nigerian context.

Respondents' importance ratings for the five bioclimatic design strategies produced the following Importance Index (II) rankings: openings and ventilation systems (II = 4.17), landscape design (II = 3.67), internal courtyards (II = 3.34), building orientation and layout (II = 3.21), and shading devices (II = 3.20). These ratings reflect occupants' behavioral awareness of the direct role of air movement in determining their thermal comfort experience, and highlight courtyards and landscaping as design elements whose passive cooling benefits are perceptibly recognized by building users.

Table 2. Summary of Bioclimatic Audit Findings and Occupant Importance Index Ratings by Strategy

Bioclimatic Strategy	Presence/awareness (%)	Adequate Implementation (%)	Best Performer	Weakest Performer	Importance Index
Openings & Ventilation	100.0	41.9	University of Ibadan	LASUSTECH	**4.17**
Landscape Design	100.0	19.4	University of Ibadan	LASUSTECH	**3.67**
Internal Courtyards	29.0	38.9	University of Ibadan	EKSU / LASUSTECH	**3.34**
Orientation & Layout	64.5	27.4	FUTA / UI	LASUSTECH	**3.21**
Shading Devices	71.0	38.7	University of Ibadan	EKSU / LASUSTECH	**3.20**

Note: FUTA = Federal University of Technology Akure; UI = University of Ibadan; EKSU = Ekiti State University; LASUSTECH = Lagos State University of Science and Technology. Source: Authors' analysis, 2026.

Predictors of Thermal Comfort Satisfaction: Regression Analysis

Multivariable ordinal logistic regression was conducted in two sequential models. Model 1 examined physiological environmental predictors; Model 2 introduced bioclimatic design strategy perception variables while controlling for environmental predictors (Table 3).

In Model 1, perceived indoor temperature emerged as the strongest predictor of thermal comfort satisfaction (β = 1.58; OR = 4.86; 95% CI [2.94, 8.03]; $p < .001$), indicating that a one-unit increase in perceived temperature was associated with a 4.86-fold increase in the odds of reporting greater thermal discomfort. Perceived indoor air velocity was the second significant predictor (β = 0.94; OR = 2.56; 95% CI [1.43, 4.57]; $p = .002$), demonstrating that improved air movement perceptions significantly increased the likelihood of thermal comfort satisfaction. The Brant test confirmed proportional odds assumptions were met for all predictors ($p > .05$).

In Model 2, with design variables introduced, building openings and ventilation exerted the greatest design-based influence on thermal comfort satisfaction (β = 1.42; OR = 4.14; 95% CI [2.51, 6.83]; $p < .001$), followed by shading devices (β = 1.11; OR = 3.03; 95% CI [1.78, 5.16]; $p < .001$), building orientation/layout (β = 0.81; OR = 2.25; 95% CI [1.37, 3.68]; $p = .001$), landscape design (β = 0.74; OR = 2.10; 95% CI [1.31, 3.36]; $p = .002$), and internal courtyards (β = 0.63; OR = 1.88; 95% CI [1.19, 2.97]; $p = .006$). All five bioclimatic design strategies were statistically significant predictors of thermal comfort satisfaction, confirming their independent and cumulative contributions to indoor thermal outcomes. Nagelkerke R^2 improved from 0.41 (Model 1) to 0.67 (Model 2), indicating substantial additional explanatory variance attributable to bioclimatic design factors.

Table 3. Multivariable Ordinal Logistic Regression: Predictors of Thermal Comfort Satisfaction

Predictor Variable	β	SE	OR (95% CI)	p	Significance
Model 1: Environmental Predictors					
Perceived Indoor Temperature	1.58	0.26	4.86 [2.94, 8.03]	<.001	***
Perceived Air Velocity	0.94	0.30	2.56 [1.43, 4.57]	.002	**
Model 2: Design Strategy Predictors					
Openings & Ventilation Systems	1.42	0.25	4.14 [2.51, 6.83]	<.001	***
Shading Devices	1.11	0.27	3.03 [1.78, 5.16]	<.001	***
Orientation & Layout	0.81	0.25	2.25 [1.37, 3.68]	.001	**
Landscape Design	0.74	0.24	2.10 [1.31, 3.36]	.002	**
Internal Courtyards	0.63	0.23	1.88 [1.19, 2.97]	.006	**

Note: OR = Odds Ratio; CI = Confidence Interval; SE = Standard Error. Model 1 Nagelkerke $R^2 = 0.41$*; Model 2 Nagelkerke* $R^2 = 0.67$*. *** $p < .001$; ** $p < .01$. Source: Authors' analysis, 2026.*

DISCUSSION

Thermal Comfort Indices and Climatic Design Context

The Evans Comfort Scale analysis confirms that Southwest Nigeria's warm-humid climate imposes severe daytime thermal stress on unshaded, inadequately ventilated buildings for seven to ten months annually, with mean maximum temperatures of 34.1–37.2°C substantially exceeding international comfort thresholds of 26–29°C for humid conditions (ASHRAE, 2020; Ogunsote et al., 2003). This finding is consistent with prior regional climate assessments (NiMet, 2025; Eludoyin et al., 2013) and reinforces the imperative for aggressive passive cooling integration as a baseline design requirement rather than an optional sustainability measure. Abeokuta's extended very hot stress profile; the most severe among the six cities suggests that buildings in Ogun State's capital require the highest passive cooling performance investment, including maximum ventilation openings, comprehensive shading systems, and robust courtyard or atrium configurations.

The Mahoney Table prescriptions derived from this analysis provide practical, location-specific design decision frameworks that extend and refine the broad guidance of the N-BEEC (NESP, 2021). The differentiation of opening requirements between Lagos (large openings: 40–80% of N/S walls) and the four inland cities (medium openings: 20–40%) reflects meaningful microclimatic variation within the region that generic national guidelines cannot capture. These findings validate the argument of Ogunsote and Prucnal-Ogunsote (2003) for region-specific rather than nationally uniform thermal comfort benchmarks in Nigeria.

Bioclimatic Implementation Deficiencies

The audit findings reveal systematic underperformance across all five bioclimatic strategy domains in the 62 assessed buildings. The near-universal provision of openings (100%) contrasted with the low adequacy of their configuration (41.9% meeting critical N/S window-to-wall ratio thresholds) demonstrates that window presence alone is insufficient- a finding consistent with Lawal (2008) and Walker (2010), who demonstrated that ventilation effectiveness depends critically on opening size, placement, and operability rather than mere presence. The prevalence of sealed or non-operable windows in buildings primarily designed for air conditioning reveals a design philosophy fundamentally at odds with the passive ventilation requirements of warm-humid climates.

The low courtyard provision (29.0%) and inadequate dimensional compliance in existing courtyards reflects a broader abandonment of climate-sensitive spatial typologies in post-colonial Nigerian institutional architecture, consistent with Adebisi et al. (2018) and Geissler et al. (2018). This trend is particularly counterproductive in the Nigerian context, where courtyards represent both a climatically optimal and culturally resonant passive cooling mechanism embedded in traditional Yoruba compound architecture that has been systematically displaced by imported rectangular block typologies (Lawal, 2008; Ogunsote et al., 2012). The superior bioclimatic performance of University of Ibadan buildings, which were primarily designed in the 1950s–1980s when climate-responsive design was more systematically practiced, further illustrates the historical regression in institutional bioclimatic design standards.

Landscape implementation, while universally present, was largely decorative rather than functional in thermal terms; an observation consistent with Ogunsote et al. (2012) and SKAT (1993). The absence of west-façade evergreen tree coverage in 80.6% of buildings is a critical oversight given that the west elevation experiences the most intense afternoon solar radiation the period identified by 59.4% of respondents as the most thermally uncomfortable.

Regression Analysis: Relative Strategy Effectiveness

The ordinal logistic regression results established the relative predictive power of all five bioclimatic strategies on occupant thermal comfort satisfaction. The primacy of opening and ventilation systems ($\beta = 1.42$; OR = 4.14) confirms the fundamental importance of natural ventilation in determining thermal comfort in warm-humid naturally ventilated buildings, consistent with Walker (2010), Jamaludin et al. (2014), and the ASHRAE adaptive comfort framework (ASHRAE, 2020). The four-fold increase in comfort satisfaction odds associated with improved ventilation perception underscores the urgency of prioritizing ventilation adequacy in both new construction and retrofit projects.

The significant and substantial influence of shading devices ($\beta = 1.11$; OR = 3.03) is consistent with Kumar et al. (2005) and Ahsan and Svane (2010), who demonstrated that effective shading can reduce indoor temperatures by 2.5–6.8°C. The three-fold comfort odds improvement associated with perceived shading adequacy confirms that shading investment delivers the highest thermal comfort return per unit expenditure after ventilation optimization; an important consideration for resource-constrained institutional procurement in Nigeria.

Building orientation and layout ($\beta = 0.81$; OR = 2.25) demonstrated significant independent influence on comfort satisfaction, consistent with Fathy (1986) and Lawal (2008), who documented 2.0–2.5°C indoor temperature reductions attributable to optimized orientation in Nigerian office buildings. The fact that orientation is a zero-cost design decision determined at the planning stage renders its systematic neglect in 35.5% of audited buildings particularly inexcusable from a value-for-money perspective.

Landscape design ($\beta = 0.74$; OR = 2.10) and internal courtyards ($\beta = 0.63$; OR = 1.88), while demonstrating lower odds ratios than ventilation and shading, nonetheless exerted statistically significant and practically meaningful influences on thermal comfort satisfaction. These results validate the compound cooling benefits of integrated landscape and courtyard design documented by Kamal (2012), Mohammed and Alibaba (2018), and confirm that their perceived absence is recognized and felt by building occupants. The hierarchical ordering of strategy influence ventilation > shading > orientation > landscaping > courtyards provides a practical prioritization framework for institutional building design and retrofit investment decision-making in warm-humid contexts.

The model's Nagelkerke R^2 improvement from 0.41 (environmental predictors alone) to 0.67 (with design strategy predictors) demonstrates that bioclimatic design quality explains an additional 26% of variance in occupant thermal comfort satisfaction beyond physiological environmental parameters. This finding is theoretically significant: it confirms that design decisions not merely climatic fate substantially determine the thermal comfort experience of institutional building occupants. Buildings with stronger bioclimatic integration consistently demonstrated better comfort outcomes, validating the core premise of passive design theory (Olgyay, 1963; Hyde, 2000) with empirical field data from a large-scale real-world institutional sample.

Policy and Practice Implications

The 69.8% thermal discomfort prevalence and the high mechanical cooling dependence (78.6% of respondents) documented in this study collectively constitute a public health, educational productivity, and energy security concern of significant magnitude. The 47.1% of respondents perceiving indoor temperatures as hot and 22.7% as very hot are consistent with prior Nigerian and West African institutional building surveys (Adunola, 2011; Ayinla & Odetoye, 2015; Ogbonna & Harris, 2008), confirming the pervasiveness of thermal discomfort in naturally ventilated Nigerian university buildings. Critically, this study demonstrates that these outcomes are substantially attributable to inadequate bioclimatic design implementation a modifiable architectural determinant rather than an immutable climatic inevitability.

The N-BEEC (NESP, 2021) requires urgent revision to incorporate the location-specific prescriptions generated by this study and to establish enforceable performance thresholds for institutional building procurement. Specifically, procurement frameworks should mandate: minimum window-to-wall ratios of 40% on N/S façades for all public university buildings; minimum 30° shading angle for overhangs and fins on all glazed openings; east-west principal axis orientation for all new institutional buildings; west-façade evergreen vegetation coverage within three years of building commissioning; and courtyard incorporation in all multi-story institutional buildings exceeding 2,000 m^2 gross floor area.

CONCLUSIONS

This study presents a comprehensive empirical assessment to date of bioclimatic design strategy effectiveness in warm-humid institutional buildings across Southwest Nigeria, integrating systematic building audits, localized thermal comfort index determination, indoor environmental measurements, and large-scale post-occupancy evaluation. The following key conclusions emerge:

1. Thermal discomfort is pervasive in Southwest Nigerian public university buildings, with 69.8% of occupants reporting hot or very hot conditions. Afternoon conditions (12:00–18:00 h) represent the critical discomfort period, driven by inadequate shading and insufficient ventilation during peak solar radiation hours.
2. All five focal bioclimatic strategies (openings and ventilation systems, shading devices, building orientation and layout, landscape design, and internal courtyards) independently and significantly predict occupant thermal comfort satisfaction in warm-humid institutional buildings. The hierarchical influence order (ventilation > shading > orientation > landscaping > courtyards) provides an empirically grounded prioritization framework for design and retrofit investment.
3. Bioclimatic design quality explains 26% of additional variance in thermal comfort satisfaction beyond physiological environmental parameters, confirming that design decisions; not merely climate substantially determine institutional building thermal outcomes.
4. The first empirically derived, location-specific thermal comfort indices and Mahoney Table prescriptions for all six Southwest Nigerian state capitals have been established, providing a

quantitative foundation for state-level building code development and the revision of the N-BEEC.

5. The University of Ibadan's superior bioclimatic performance attributable to its historically climate-responsive building design demonstrates that passive design integration in warm-humid institutional buildings is both technically feasible and demonstrably effective in improving occupant thermal comfort outcomes.

The findings carry significant implications for architectural practice, building regulation, and sustainability policy in Sub-Saharan Africa. Specifically, universities must be mandated to adopt comprehensive bioclimatic design frameworks as conditions for institutional building procurement approval. State and federal building codes should incorporate the location-specific prescriptions generated by this study. The N-BEEC should be revised to include enforceable institutional building performance standards with post-occupancy verification requirements. Architectural education should reinforce bioclimatic design competencies as core professional capabilities for practitioners working in warm-humid tropical contexts.

Future research should examine the long-term thermal performance of bioclimatically retrofitted institutional buildings using longitudinal post-occupancy monitoring, develop simulation-validated courtyard design optimization models for Nigerian university campuses, and investigate the integration of passive cooling strategies with low-carbon renewable energy systems to achieve net-zero energy institutional buildings in warm-humid Sub-Saharan Africa.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

I.I. Adebisi: Conceptualization, methodology, data collection, formal analysis, writing (original draft).

A.K. Ayinla: Supervision, resources, writing (review and editing).

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