INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

Passive Cooling and Thermal Comfort Optimization in University Student Centres in South-South Tropical Climates

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DOI: https://doi.org/10.51584/IJRIAS.2026.11060271

Received: 27 June 2026; Accepted: 02 July 2026; Published: 16 July 2026

ABSTRACT

University student centres serve as important academic, social, and recreational spaces that support student well-being and campus life. However, maintaining thermal comfort within these facilities remains a significant challenge in South-South Nigeria due to high temperatures, elevated humidity levels, and intense solar radiation. This study investigates thermal optimization strategies for the design of sustainable student centres in the south-south tropical climates. Many existing university student buildings rely heavily on mechanical cooling systems, leading to high energy consumption and increased operational and maintenance costs. Using a qualitative research design comprising a review of literature and a comparative case study analysis, To strengthen the climatic relevance of the comparative evidence, the case study base combines two temperate-climate examples (Trent University Student Centre, Canada, and Cleveland State University Student Center, USA) with two hot-humid and equatorial tropical examples that are more directly analogous to Port Harcourt: the SDE4 building at the National University of Singapore and the Kéré Architecture-designed Startup Lions Campus in Turkana, Kenya. the research evaluates architectural strategies such as natural ventilation, shading systems, building orientation, and material selection to improve indoor environments. Findings from the reviewed literature and case studies indicate that building orientation, natural ventilation, atrium-based airflow systems, solar shading devices, and high-performance building envelopes contribute significantly to improved thermal comfort and reduced dependence on mechanical cooling systems. The paper integrated insights from sustainable design practices, highlighting the balance between architectural aesthetics, economic efficiency, and environmental responsibility. Ultimately, this work proposed a climate-responsive passive cooling framework for university student centres in South-South Nigeria. As the study is qualitative and comparative rather than measurement- or simulation-based, its outcomes are presented as anticipated performance, and the paper concludes with an explicit call for future mixed-methods research using building performance simulation and field measurement to quantitatively validate the proposed framework.

Keywords: Passive cooling, Student centres, Thermal comfort, Natural ventilation, Energy efficiency mechanical systems.

INTRODUCTION

University student centres are vital multipurpose facilities designed to facilitate learning, social interaction, recreation and student development. In addition to supporting academic and social activities, student centres should be designed as inclusive environments that provide equitable access and opportunities for all categories of users. Studies on the accessibility of built environments in Port Harcourt have shown that social inclusion is a critical indicator of sustainable architectural development and user satisfaction (Dimkpa et al., 2024). However, maintaining a suitable indoor environment in these spaces is exceptionally challenging in tropical regions, where constant high temperatures, intense solar radiation, and high humidity prevail (Okonkwo & Adamu, 2021). In the South-South region of Nigeria, these environmental factors often lead to severe indoor overheating, which has been shown to negatively impact students' cognitive productivity, physiological well-being, and overall campus experience (Humphreys et al., 2020).

Historically, thermal discomfort in Nigerian institutional buildings has been addressed through a heavy reliance on mechanical air conditioning systems. While effective in the short term, these systems pose significant sustainability challenges due to their high energy demand and exorbitant operational and maintenance costs (Adebayo, 2023). Furthermore, the World Green Building Council (2022) emphasizes that over-reliance on mechanical cooling contributes to the "urban heat island" effect and increases the carbon footprint of educational institutions.

Passive cooling strategies offer a sustainable alternative by utilizing natural environmental variables to regulate indoor temperatures with minimal dependence on artificial systems. These strategies emphasize building orientation, natural ventilation, strategic shading, and the use of thermal mass to reduce heat gain and promote heat dissipation (Givoni, 2017). When correctly implemented, passive design not only enhances indoor thermal conditions but also aligns with the global shift toward net-zero energy buildings.

Therefore, optimizing passive cooling in university student centers is both a technical necessity and an environmental imperative. This study explores design-based interventions tailored to the specific climatic conditions of the South-South tropical zone, aiming to achieve a balance between user-centered comfort and environmental responsibility.

Statement Of Problem

The prevalent dependence on mechanical cooling systems student centres not only increases energy consumption but also imposes significant financial burdens on institutions. Furthermore, deficiencies in natural ventilation, excessive solar heat gain, and inefficient material selection contribute to elevated indoor temperatures, poor air quality, and reduced occupant comfort. These conditions ultimately diminish user satisfaction and hinder the functional performance of such facilities. Despite the growing emphasis on sustainable building practices, there remains a lack of comprehensive, context-specific design frameworks that effectively incorporate passive cooling strategies in student centres. This gap limits the ability of buildings to achieve an optimal balance between thermal comfort and energy efficiency. Compounding this gap, much of the comparative material previously used in this field of study comes from temperate regions, necessitating further review against hot-humid and equatorial tropical precedents that share Port Harcourt's environmental characteristics.

Therefore, there is a critical need to evaluate and develop appropriate passive cooling strategies to enhance indoor environmental quality in university student centres within South-South tropical climates.

Research Aim

To examine passive cooling strategies suitable for improving thermal comfort in university student centres located in South-South tropical climates through qualitative analysis of literature and selected case studies, from both temperate and hot-humid tropical contexts.

Objectives Of The Study

1. To review passive cooling principles applicable to tropical student centre buildings: Assess the impact of specific passive cooling techniques (such as shading, thermal mass, or natural ventilation) on indoor temperature fluctuations within university facilities.

2. To Examine Levels of Thermal Comfort: Analyse how much passive design techniques enhance occupant comfort in terms of humidity, temperature, and airflow.

3. To assess the perceived thermal comfort benefits of these passive strategies

4. To Assess Occupant Perception: Investigate user satisfaction and qualitative experiences regarding the usability and comfort of passively cooled academic environments.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

Research Questions

1. How can passive cooling strategies be effectively integrated into university student centres to improve thermal comfort in South-South tropical climates?

2. How do natural ventilation configurations and solar shading systems quantitatively affect occupant thermal comfort thresholds?

3. What is the benefits of passive design strategies that could enhance thermal comfort?

4. What are the prevailing occupant perceptions regarding the functional usability and environmental quality of passively cooled university spaces?

LITERATURE REVIEW

The Paradigm of Passive Cooling in Tropical Climates

Passive cooling refers to architectural strategies that harness natural climatic elements such as wind, shade, and thermal mass—to maintain comfortable indoor temperatures without mechanical energy input (Ozone Cell, 2024). In the hot and humid contexts of South-South tropical regions, these techniques have transitioned from traditional vernacular wisdom to a critical modern design imperative. Rapid urbanization and rising energy demands have exposed the limitations of conventional mechanical cooling, making environmentally responsive design essential for sustainability (Cheshmehzangi & Dawodu, 2020). The growing emphasis on sustainable architecture has further reinforced the need for climate-responsive building strategies that reduce resource consumption and environmental impacts. According to Dimkpa, Ohochuku, and Adibe (2023), achieving sustainability in the built environment requires a circular synergy that integrates resource efficiency, environmental stewardship, and context-sensitive design solutions. Their study highlights the importance of architectural approaches that minimize dependence on energy-intensive systems while promoting long-term environmental resilience. These principles support the adoption of passive cooling strategies in university student centres, particularly within tropical climates where reducing cooling loads is critical to sustainable building performance.

Scholarly research indicates that integrating passive cooling can achieve significant energy savings, with some studies demonstrating a reduction in cooling energy demand by up to 40% (Ochedi & Taki, 2022). Despite these benefits, implementation in regions like Nigeria remains uneven due to regulatory challenges and limited technical expertise (Emodi et al., 2025; SEforALL, 2023).

Thermal Comfort in Educational Buildings

Thermal comfort in tropical university settings is a dynamic negotiation between climatic variables and human adaptation. While ASHRAE (Standard 55) historically set rigid physical criteria for humidity and temperature, field studies in tropical climates reveal that occupants of naturally ventilated buildings often report higher satisfaction levels at higher temperatures than those in air-conditioned spaces (ANSI/ASHRAE, 1992).

Climatic and Architectural Determinants

The effectiveness of a student centre is governed by how it mediates local environmental factors. In humid tropics, relative humidity is the primary antagonist, as it inhibits the body's natural evaporative cooling mechanisms, thereby intensifying the sensation of heat (Prescott, 1998).

- **Orientation and Geometry:** Proper alignment along the east-west axis is a thermal necessity. Minimizing exposure to low-angle morning and afternoon sun reduces the solar load on building facades (Ergün & Bekleyen, 2024).

- **Material Selection:** The thermal properties of the building envelope, including conductivity and reflectivity, dictate heat gain. While thermal mass can buffer temperature swings, its success in humid

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

climates is dependent on effective night-time ventilation to prevent heat retention (Muhammad Usman Kanoma et al., 2021).

Integrated Passive Cooling Strategies

A holistic design approach for university student centres requires a combination of context-specific interventions.

Advanced Ventilation Design

Natural ventilation remains the cornerstone of tropical design. It relies on wind-driven pressure differentials and buoyancy-driven stack effects to flush out warm air (Lechner, as cited in Advances in Passive Cooling Design, 2020). Cross-ventilation is highly effective for air exchange, while stack ventilation facilitates vertical airflow in multi-story educational buildings.

Solar Control and Shading

Shading is the first line of defense against direct solar radiation. Strategies include fixed devices like overhangs and vertical fins, as well as green infrastructure. Trees and green facades provide "living" shading while contributing to evaporative cooling through evapotranspiration (Nzube & Lyu, 2021).

Evaporative and Emerging Techniques

While direct evaporative cooling is less effective in high-humidity zones, indirect methods—such as the use of water bodies and vegetated courtyards—can modify the microclimate of semi-outdoor spaces (Oleiwi et al., 2023). Emerging techniques like **Cool Roofs** and **Green Roofs** are also gaining traction for their ability to reflect radiation and provide natural insulation (Nzube & Lyu, 2021; Oleiwi et al., 2023).

Previous studies have demonstrated through simulation and empirical investigations that passive cooling strategies can improve thermal performance and reduce dependence on mechanical cooling systems.

Study Area

The study was conducted in Port Harcourt, the capital of Rivers State, situated in the South-South region of Nigeria. Port Harcourt is a major urban and economic centre in the Niger Delta, widely recognized for its role in Nigeria’s oil and gas industry. Over the past two decades, the city has experienced rapid population growth and urban expansion, resulting in increased demand for educational, social, and recreational infrastructure. It hosts several higher institutions, including Rivers State University, making it a significant hub for student population and academic activities.

Geographically, Port Harcourt lies approximately between latitudes 4°45′N and 4°55′N and longitudes 6°55′E and 7°05′E. The city is characterized by low-lying terrain, with an average elevation of less than 20 meters above sea level. It experiences a tropical monsoon climate marked by high humidity, intense rainfall between March and November, and average temperatures ranging from 25°C to 31°C. These climatic conditions present important design considerations for a university student center, particularly in relation to passive cooling, natural ventilation, moisture control, and material durability. Proper architectural responses are essential to ensure thermal comfort and long-term functionality of the facility.

From a socio-cultural perspective, Port Harcourt is a cosmopolitan city with a diverse population of students, professionals, and residents from various ethnic and cultural backgrounds. Social interaction, collaboration, and extracurricular engagement are integral aspects of student life, especially within Rivers State University. However, many university campuses face challenges related to inadequate communal spaces for relaxation, interaction, and student-led activities. This has created a growing need for well-designed student centres that can serve as hubs for academic support, social engagement, and recreational use.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

Consequently, the proposed university student centre is envisioned as a multi-functional facility that accommodates a wide range of student needs, including study areas, meeting spaces, lounges, and event halls. The design must respond to both the environmental conditions of Port Harcourt and the dynamic lifestyle of its student population, incorporating flexible layouts, climate-responsive strategies, and inclusive spatial planning to enhance user comfort and overall campus experience.

RESEARCH METHODOLOGY

This research employs a **qualitative research design** focused on the critical evaluation of passive cooling integration in academic environments. The methodology is structured into

Comparative Case Study Analysis: To bridge the gap between theory and practice, four case studies were chosen utilizing a purposeful, two-tier sampling strategy. The first tier includes two well-documented institutional student/campus facilities in temperate climates: **Trent University Student Centre (Canada)** and **Cleveland State University Student Center (USA),** which were chosen for their mature, well-published examples of atrium- and stack-effect-driven passive design in large-scale educational buildings. The second tier, added specifically to address the climatic limitations of relying solely on temperate precedents, consists of two facilities in hot-humid and equatorial tropical settings that are climatically similar to Port Harcourt: **the SDE4 building at the National University of Singapore**, located in a hot-humid tropical climate, and **the Startup Lions Campus in Turkana, Kenya,** an equatorial East African educational and training facility designed by Kéré Architecture.

It is critical to emphasize that this remains a qualitative, literature- and precedent-based methodology. This study did not include any physical measurements, occupant surveys, or computational building performance simulations; all thermal and comfort outcomes reported for the case studies are based on previously published accounts, and the outcomes proposed for Port Harcourt are presented as anticipated rather than measured or simulated performance.

Case Study Review

A. Temperate Climate Case Studies

Trent University Student Centre (Canada)

- **Design and Configuration**

Designed by Teeple Architects, the building features a high-performance building envelope with a distinctive **photo-etched precast concrete** and glass facade. It utilizes a deep floor plan with a large central atrium designed to pull natural light and air deep into the structure.

- **Thermal Performance**

The building leverages **natural ventilation** through the atrium, acting as a solar chimney. Strategic shading on the glazed facades minimizes solar heat gain during the summer while allowing for passive heating in the winter.

- **Energy Efficiency**

By integrating a high-thermal-mass exterior and natural air circulation, the center significantly reduces the load on mechanical cooling systems during transitional seasons.

- **User Experience**

Occupants report high satisfaction with the "breathability" of the space. The connection to the Otonabee River provides both a psychological cooling effect and a source for natural breezes.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

Cleveland State University Student Center (USA)

- **Design and Configuration**

The CSU Student Center features a massive **glass curtain wall** and a large open interior "street" or atrium. It utilizes transparent design to maximize daylighting while employing integrated louvers and high-performance glazing to control thermal intake.

- **Thermal Performance**

The facility uses **stack ventilation** principles within its multi-story atrium to exhaust hot air. The building's orientation is optimized to utilize the "canyon effect" of the surrounding urban fabric to channel airflow.

- **Energy Efficiency**

The use of automated shading and daylight harvesting reduces the need for artificial lighting and supplemental cooling, leading to lower peak energy demand.

- **User Experience**

Students value the transparency and thermal consistency of the communal "city side" lounges, though some note localized "hot spots" near unshaded glass sections during high-noon periods.

B. Hot-Humid and Equatorial Tropical Case Studies

SDE4, National University of Singapore (Singapore)

- **Design and Configuration:** SDE4 is a six-storey, net-zero-energy educational building at the National University of Singapore, designed by Serie + Multiply Architects with Surbana Jurong. Its climate-responsive form uses verandas, terraces, and landscaped balconies drawn from tropical vernacular precedent to promote cross-ventilation and shade the building mass.
- **Thermal Performance:** Only a minority of the building is fully air-conditioned; a substantial proportion of the floor area is naturally ventilated, with the remainder served by a hybrid "mixed-mode" system that supplies pre-cooled fresh air at an elevated set-point temperature, augmented by ceiling fans that raise air speed rather than lowering temperature alone.
- **Energy Efficiency:** The hybrid tempered approach is reported to use markedly less energy than a conventional fully air-conditioned design of similar size, with the building's roof-mounted photovoltaic array offsetting the balance of its energy demand.
- **User Experience:** Post-occupancy accounts describe the transitional verandah and terrace spaces as central to occupant comfort, with operable facades allowing occupants to shift between natural ventilation and hybrid cooling depending on conditions — an adaptive-comfort model directly relevant to Port Harcourt's communal student-centre spaces.

Startup Lions Campus, Turkana, Kenya

- **Design and Configuration:** Designed by Kéré Architecture and completed in 2021, this educational and technology-training campus on the shores of Lake Turkana uses tall, conical ventilation towers inspired by local termite-mound structures, combined with thick, locally sourced quarry-stone walls.
- **Thermal Performance:** The towers function as thermal chimneys, drawing warm air upward and out of the building while cool air enters through small, angled, low-level openings, achieving a stack-driven crossflow without any mechanical cooling.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

- **Energy Efficiency:** The building operates entirely without air conditioning despite housing heat-sensitive IT equipment, relying instead on the combination of thermal mass, the stack effect, and carefully proportioned low-level openings that also exclude dust.

- ***User Experience and Cost:*** The project deliberately prioritized locally available, low-cost materials and construction techniques over imported high-performance systems, illustrating that effective passive cooling in a resource-constrained, tropical, low-income setting can be achieved without expensive imported technology — a consideration directly relevant to the Nigerian economic context discussed later in this paper.

Comparative Analysis

All four case studies use the atrium- or tower-driven stack effect as their primary passive cooling method, although they differ in how they handle thermal mass, glass, and cost. Trent University regulates temperature using precast concrete's thermal mass; Cleveland State uses advanced glazing and a large internal air volume; SDE4 combines a lightweight, highly ventilated envelope with a hybrid mechanical backup rather than relying solely on mass; and the Startup Lions Campus relies almost entirely on thick local masonry and passive stack with no mechanical assistance.

This deviation is useful for Port Harcourt. The temperate case studies show that atrium-driven ventilation and thermal mass can function successfully in areas where nighttime temperatures drop enough to "flush" stored heat from the building fabric. The tropical case studies, on the other hand, demonstrate two distinct solutions to the problem of a climate with limited night-time cooling: SDE4 combines a lightweight, highly permeable envelope with a modest hybrid backup system tuned to a higher comfort set-point, whereas the Startup Lions Campus combines high thermal mass with an aggressive, unassisted stack-ventilation system and dust-excluding low-level inlets. Both tropical antecedents, therefore, provide more climatically believable blueprints for Port Harcourt than the temperate ones alone, and both attained their results without resorting to the most expensive high-performance glazing or imported mechanical systems typical of the temperate case studies.

Results from Case Study

- Thermal Performance: Across all four case studies, atrium- or tower-based airflow facilitates effective air movement, moderating temperatures in high-occupancy communal areas; the tropical examples achieve this without dependence on cool night-time air to recharge thermal mass.

- Ventilation: Automated and manual natural ventilation points are essential for purging heat during the day; in the tropical case studies, ventilation openings are additionally designed to exclude dust and manage very high daytime humidity.

- Energy Efficiency: Passive strategies in the temperate centers reduce HVAC runtime mainly in the transitional seasons, whereas the tropical case studies (particularly Startup Lions Campus) demonstrate that a near-total avoidance of mechanical cooling is achievable year-round in a hot climate when the envelope and ventilation strategy are correctly matched to conditions.

- Cost and User Comfort: The tropical case studies show that occupant comfort and full or partial passive operation can be achieved using low-cost local materials (Startup Lions Campus) or a modest hybrid system tuned to a higher, adaptive comfort set-point (SDE4), rather than requiring the high-specification glazing and automated systems used at Cleveland State.

Ethical Approval

No ethical approval was obtained for research because there was no involvement of human subjects or animals.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

Conflict of Interest

There were no potential conflicts of interest.

RESULTS

The qualitative analysis of literature and comparative evaluation of the four selected case studies yielded the following key findings regarding passive cooling and thermal optimization:

- The Efficacy of the Atrium/Tower as a Thermal Regulator: All four case studies demonstrate that a central atrium or ventilation tower serves as more than an aesthetic feature; it acts as a functional solar chimney. By utilizing the stack effect, these spaces facilitate the vertical movement of warm air, resulting in a reduction in ambient temperature within ground-floor communal zones — an effect reported in both temperate buildings and, notably, in the fully passive, mechanically-unassisted Startup Lions Campus in an equatorial climate.

- Building Envelope and Materiality: At Trent University, the use of high-thermal-mass precast concrete was found to stabilize internal temperatures by absorbing heat during peak radiation periods, an approach echoed in the thick quarry-stone walls of the Startup Lions Campus. In contrast, Cleveland State's and SDE4's reliance on advanced glazing, automated louvers, or a lightweight, highly ventilated envelope highlights the importance of the building skin in controlling solar heat gain while maximizing daylight and airflow.

- Natural Ventilation and Energy Mitigation: Data from the case studies indicate that integrated passive strategies — natural air circulation, stack-driven exhaust, and, where used, night-time purging — significantly reduce or eliminate HVAC runtime. This effect was most consistent in transitional seasons for the temperate examples, but was sustained year-round in the tropical examples, suggesting strong potential for adaptation to Port Harcourt's climate.

- User Satisfaction and Perceived Comfort: Occupant feedback across the case studies revealed a direct association between "fresh air" perception and high satisfaction levels. The presence of natural light and "breathable" spaces improved the psychological and physiological quality of the study environment, even when temperatures were above conventional mechanical setpoints, consistent with adaptive comfort principles reported for naturally ventilated tropical buildings in the literature (Humphreys et al., 2020).

- Cost Sensitivity: The tropical case studies indicate that effective passive cooling does not necessarily require the highest-specification (and most expensive) glazing or automated systems; locally sourced materials and simple, well-proportioned openings can achieve comparable or superior passive performance at lower capital cost, a finding directly relevant to the economic constraints discussed in the Cost-Benefit Considerations section below.

DISCUSSION

The findings of this research underscore a critical shift from mechanical dependence to climate-responsive design. While the case studies (Trent and Cleveland) are situated in temperate regions, their architectural logic provides a robust framework for adaptation to the South-South tropical climate of Nigeria. The findings also align with previous research on environmental performance and interior habitability in Nigerian urban housing. Ohochuku, Dimkpa, and Pyamene (2025) observed that inadequate natural lighting and poor environmental planning contribute significantly to occupant dissatisfaction and the paradox of abandoned interior spaces despite increasing rental values. This further reinforces the importance of integrating natural applications such as daylighting systems, passive ventilation, and climate-responsive architectural strategies into sustainable housing development in Port Harcourt

The Role of Natural Ventilation in Humid Tropics

The success of the stack effect in the case studies suggests that for student centres in Port Harcourt, verticality and open-plan atriums are essential. However, unlike temperate regions, the high humidity of the South-South zone requires a higher velocity of airflow to facilitate evaporative cooling on the skin. Therefore, the "atrium-as-chimney" model must be paired with wide **cross-ventilation** apertures to ensure constant air movement.

Materiality and the Thermal Mass Paradox

The research highlights a divergence in material strategy. While Trent University successfully uses thermal mass, in a tropical monsoon climate like Port Harcourt — where night-time temperatures remain high — high thermal mass can inadvertently trap heat unless paired with aggressive night ventilation, as is achieved at the Startup Lions Campus through its stack towers. The discussion suggests that for the Nigerian context, a hybrid approach combining the Cleveland State/SDE4 model of high-performance or highly ventilated building skins and shading with the Startup Lions Campus model of thermally massive, locally sourced walls paired with dedicated stack-ventilation towers may be more effective than either strategy applied in isolation.

Synthesizing Aesthetics and Energy Efficiency

A common theme in the results is the balance between transparency and thermal load. The "hot spots" noted at Cleveland State serve as a cautionary finding for tropical designs; large glass curtain walls in Port Harcourt would require aggressive **external shading devices** (fins or overhangs) to prevent the greenhouse effect, confirming the literature review’s emphasis on orientation along the east-west axis.

Proposed Passive Cooling Strategy for Student Centres in South-South Nigeria

Based on findings from the reviewed literature and the case studies, a five-component passive cooling strategy is proposed:

1. Climate-Responsive Building Orientation

- Long façades facing north-south
- Reduced east-west solar exposure

2. Enhanced Cross Ventilation

- Large operable windows
- Opposing openings
- Open interior circulation

3. Central Atrium Ventilation System

- Atrium acting as thermal chimney
- Warm air exhausted through roof vents

4. Integrated Shading System

- Horizontal overhangs
- Vertical fins
- Vegetation buffers

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

5. High-Performance Building Envelope

- Reflective roofing materials
- Insulated wall systems
- Reduced glazing ratios

Perceived Performance of the Proposed Strategy

Drawing lessons from all four case studies, the proposed strategy is expected to perform as summarised below.

Strategy	Expected Performance
Orientation	Reduced solar heat gain
Cross ventilation	Improved air movement
Atrium/tower ventilation	Enhanced heat extraction
Shading systems	Lower indoor heat penetration
Building envelope	Increased thermal stability

Source: Authors' analysis and conclusion, 2026

Because this study is qualitative and precedent-based, these outcomes are described as perceived or anticipated performance rather than measured or simulated performance. This distinction is intentional and is discussed further below.

Limitations of The Study

This study has three principal limitations that should be considered when interpreting its findings and recommendations.

- First, no case study is located within Port Harcourt's specific tropical monsoon sub-climate, and differences in humidity regime, rainfall pattern, and night-time temperature retention between these precedents and Port Harcourt mean that the transferability of their outcomes remains indicative rather than guaranteed.
- Second, this study is entirely qualitative. It relies on documented literature and secondary case study accounts rather than on physical measurements, occupant thermal comfort surveys, or computational building performance simulation. As such, it cannot quantitatively confirm that the proposed five-component strategy will achieve specific thermal comfort thresholds (for example, defined operative temperature or PMV/PPD ranges) in Port Harcourt; its outcomes are, and should be read as, anticipated rather than proven performance.

RECOMMENDATIONS FOR FUTURE RESEARCH

To directly address the limitations above, future work building on this study should:

- Adopt a mixed-methods design that combines the qualitative and comparative approach used here with quantitative building performance simulation (for example, using EnergyPlus, IES-VE, or Design Builder) calibrated to Port Harcourt's climate data, to test whether the proposed five-component strategy achieves specific thermal comfort thresholds.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VI June 2026

- Where possible, incorporate field measurement or post-occupancy evaluation of an existing or pilot student centre in Port Harcourt or a climatically similar South-South Nigerian city, to validate simulated predictions against real occupant experience.

- Expand the comparative case study base further to include additional hot-humid tropical and equatorial African precedents (for example, in West and Central Africa or Southeast Asia) to build a larger, more climate-matched evidence base than the two temperate and two tropical examples used here.

- Conduct a detailed, quantified cost-benefit analysis of the tiered implementation strategy proposed in this paper, using current Nigerian material and labour costs, prevailing electricity tariffs, and standard payback-period or life-cycle-cost methods, in consultation with local quantity surveyors and university facilities managers.

CONCLUSION

This study concludes that passive cooling is not merely an alternative to mechanical systems but a fundamental requirement for sustainable campus architecture in tropical regions. The comparative analysis of global case studies reveals that thermal comfort is most effectively achieved through an integrated building envelope that manages light, heat, and air holistically.

The following recommendations are proposed for the design of student centers in South-South Nigeria:

1. **Prioritize the Stack Effect:** Incorporate central atriums to exhaust accumulated heat, reducing the thermal load on communal lounges.

2. **Optimize Orientation:** Align structures to minimize east-west solar exposure while maximizing northern and southern openings for natural light and wind.

3. **Adopt Adaptive Comfort Standards:** Move away from rigid mechanical cooling setpoints in Favor of naturally ventilated spaces that offer "adaptive opportunities" (operable windows and shaded semi-outdoor areas).

4. **Integrated Shading:** Utilize external louvers, vegetation, and locally sourced thermally massive materials to mitigate solar radiation before it reaches the building envelope, prioritising the lowest- and mid-cost tiers identified in the Cost-Benefit Considerations section.

By implementing these climate-responsive strategies, student centres in Port Harcourt can reduce operational costs, lower their carbon footprint, and provide students with a healthier, more productive environment for learning and social engagement.

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