International Journal of Multidisciplinary Research and Growth Evaluation.

Addressing Framework Gaps in Climate-Responsive Passive Design: Toward a Replicable Model for Educational Buildings in the Tropical Climate of Owerri, Nigeria

Bartholomew Nonso Nwafor [1*], Steve Ikpendu Nwankwo [2], Solomon Oisasoje Ayo-odifiri [3], Jude Chisom Olemgbe [4]
[1-4] Department of Architecture, Federal University of Technology, Nigeria

* Corresponding Author: **Bartholomew Nonso Nwafor**

Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 7.98
Volume: 06
Issue: 05
September - October 2025
Received: 03-08-2025
Accepted: 04-09-2025
Published: 29-09-2025
Page No: 669-678

Abstract
Climate-responsive passive design is critical for long-term educational infrastructure in tropical nations, but there is still a significant gap between established concepts and their actual application in local contexts. This study investigates the inadequacies of existing sustainability frameworks when applied to school buildings in Owerri, Nigeria, a hot and humid climate. This study uses a novel methodological approach to identify critical gaps in globally recognised systems such as LEED and EDGE, as well as Nigerian building codes, in terms of specificity, climatic nuance, and implementability. The approach combines comparative framework analysis, contextual interpolation of secondary climatic and architectural data, and interpolated simulation results from peer-reviewed EnergyPlus-based studies.
The study's primary contribution is its ability to synthesise these facts and present a novel, reproducible technique that blends progressive design stages with actionable, context-specific passive tactics. According to the findings, the proposed approach can bridge the theory-practice divide by providing architects and policymakers with a structured yet customisable path, potentially reducing cooling energy consumption by 20-40% based on synthesised simulations. This is significant because it provides a scalable blueprint for reducing energy consumption and enhancing thermal comfort in educational settings across West Africa, helping to achieve SDGs 4 (Quality Education) and 11 (Sustainable Cities and Communities). The paper concludes that a context-interpolated framework is not only beneficial, but also necessary, for achieving real sustainability in tropical educational architecture.

DOI: https://doi.org/10.54660/.IJMRGE.2025.6.5.669-678

Keywords: Passive Design, Climate-Responsive Architecture, Educational Buildings, Tropical Climate, Owerri, Sustainability Frameworks, Replicable Model, Nigeria

1. Introduction

The worldwide building sector accounts for over 40% of total energy consumption and greenhouse gas emissions (International Energy Agency, 2020) [15]. This impact is exacerbated in tropical regions by the extensive use of energy-intensive mechanical systems to provide indoor thermal comfort in structures that are inappropriate for the local environment. This challenge is especially acute in educational facilities, as the indoor environment has a direct impact on cognitive function, student attendance, and academic accomplishment (Wargocki & Wyon, 2013; Zomorodian *et al.*, 2016) [29, 33]. In Nigeria, which has a rapidly growing young population and a high demand for educational infrastructure, school development usually prioritises speed and low beginning costs over long-term environmental performance (Adegun & Olusina, 2019) [2]. This has resulted in an excess of educational facilities that are thermally uncomfortable, costly to operate, and ultimately detrimental to their teaching goals.

A viable alternative is climate-responsive passive design. Passive design can significantly reduce, if not eliminate, the need for mechanical cooling by using natural energy sources like sunlight, wind, and light to maintain comfort (Givoni, 1998; Lechner,

2014) [14, 18]. The concepts for hot-humid climates, such as Owerri, Imo State, are well documented: limit solar heat gain, promote natural ventilation, and use appropriate construction materials (Ogunsote *et al.*, 2021) [20]. However, there is a substantial gap between these theoretical concepts and their practical application in practice. This theory-practice gap demonstrates that present paradigms for sustainable design, both global and local, are unable to meet the unique contextual difficulties of regions like Southeast Nigeria.

This study looks into the specific gaps in existing sustainable design frameworks when applied to educational buildings in Owerri's tropical climate. It employs a rigorous technique for comparative framework analysis and contextual interpolation of secondary data, which is supplemented with interpolated EnergyPlus simulation insights from similar Nigerian studies to validate possible energy reductions. The study's originality stems from its critical synthesis of global standards with hyper-local climatic and socio-technical elements to produce a uniquely fitted, reproducible model, an approach that is mostly absent from prior literature. Compared to other tropical models (for example, those for residential structures in hot-humid regions), the OPDF emphasises educational-specific modifications such as variable occupancy in classrooms, distinguishing it from general frameworks used in Malaysia and India. The study revealed that current frameworks lack the necessary specificity and contextual sensitivity, leading to poor building performance. The proposed approach addresses this by providing an organised, staged guide for designers and policymakers, as well as a practical method for improving building sustainability, improving educational outcomes, and lowering the carbon footprint of Nigeria's educational infrastructure, with quantified reductions in indoor temperatures (e.g., 2-4°C) and cooling loads (20-40%) based on synthesised data.

This article is organised into the following sections: a literature review of relevant frameworks and passive design theory; a detailed explanation of the methodology; a presentation of the findings, including gap identification and the proposed model; a discussion of implications; and a conclusion with recommendations.

2. Literature Review

2.1. Global Sustainability Frameworks and Their Applicability in the Tropics

There are several significant frameworks that govern sustainable building design around the world. LEED (Leadership in Energy and Environmental Design) is probably the best-known, with a point-based system that includes categories including Energy & Atmosphere and Indoor Environmental Quality (USGBC, 2021) [27]. While comprehensive, LEED has been criticised for its one-size-fits-all approach, which may undervalue passive measures that are highly effective in certain places such as the tropics but contribute little to point acquisition (Doan *et al.*, 2017) [11]. For example, a deeply shaded veranda, a defining tropical feature, may not be explicitly rewarded in the same way that a high-efficiency HVAC system is.

The International Finance Corporation (IFC) created EDGE (Excellence in Design for Greater Efficiencies), which is largely geared towards emerging markets. It aims to quantify reductions in energy usage, water consumption, and material embodied energy (IFC, 2021) [16]. The EDGE software provides a user-friendly interface for simulating these reductions. However, its primary focus is on quantifiable energy savings, which may favour technological solutions over passive, non-mechanical ways that provide comfort while consuming little energy (Alyami *et al.*, 2020) [5]. Its climate data, while improved, may fail to capture the microclimatic characteristics of a single site, such as Owerri. Other frameworks, such as BREEAM (Building Research Establishment Environmental Assessment Method) and Green Star, share characteristics with LEED in that they are comprehensive yet frequently require adaptation for maximum performance in non-temperate settings. The fundamental criticism is that, while aspirational, these frameworks may be misapplied in the Global South, resulting in buildings certified "green" but neither culturally suitable or resilient (Bond & Perolini, 2019) [7].

2.2. Nigerian Building Codes and Local Guidelines

Nigeria's main regulatory documents are the National Building Code (NBC) and state-level urban development codes. The National Building Code (NBC) defines the fundamental principles for health, safety, and welfare in building design. However, it is notoriously out of date and poorly executed (Olotuah and Bobadoye, 2019) [23]. Its energy efficiency and environmental performance standards are limited and do not provide the clarity required for true climate-responsive design. For example, while it states "adequate ventilation," it does not specify the necessary air change rates or procedures for achieving them in a hot, humid environment.

Research on Nigerian architectural practices continually demonstrate a reliance on imported Western building models that value aesthetics above functional design (Ugwu, 2015) [28]. Many practitioners acknowledge a knowledge gap in the technical specifics of passive approaches, such as shade device sizing and cross-ventilation engineering (Onyenokporo, 2017) [24]. The combination of permissive regulation and a lack of technical skill creates a significant barrier to the adoption of excellent passive architecture.

2.3. Principles of Climate-Responsive Passive Design for Hot-Humid Climates

The bioclimatic design concept for hot and humid environments is well known. The fundamental goals are to: (1) minimise or reduce heat input within the structure; and (2) maximise heat loss and promote cooling, mostly through air movement (Szokolay, 2014) [26]. Key strategies include:

Building Orientation and Form: Extending the structure along an east-west axis to decrease the exposure of larger wall sections to the low-angle east and west sun. A thin, single-bank arrangement (ideally less than 8-10m deep) is necessary to allow for cross-ventilation (Ogunsote & Prucnal-Ogunsote, 2019) [21].

Solar shading: This is necessary. Horizontal shading devices (e.g., overhangs, louvres) are effective on north and south facades, but vertical or egg-crate devices are necessary for east and west elevations to block the low-angle sun (Echendu, 2022) [12].
Natural ventilation: In humid conditions, increasing air movement is critical for thermal comfort. This includes designing for cross-ventilation (inlets on the windward side, outlets on the leeward side) and, when possible, stack ventilation to exhaust hot air (Okafor, 2020) [22].
Material Selection: Using materials with low thermal mass (e.g., lightweight concrete and timber) helps the building to cool quickly overnight. Light-colored, reflective roofs and walls help to reject solar radiation (Kumar *et al.*, 2017).

Table 1: Comparison of Existing Sustainability Frameworks for Tropical Application

Framework	Origin	Key Focus	Strength	Weaknesses for Owerri's context
LEED	U.S.	Holistic sustainability (energy, water, materials, IEQ).	Market recognition, comprehensive checklist.	Generic, points system may not prioritize key passive strategies; high cost of certification.
EDGE	IFC (World Bank)	Resource efficiency (energy, water, materials).	Tailored for emerging markets, user-friendly software.	Overemphasis on quantifiable energy savings may sideline non-mechanical passive cooling.
BREEAM	UK	Holistic sustainability, life-cycle assessment.	Robust, science-based.	Like LEED, developed for temperate climates, requires significant adaptation.
Nigeria Building Code	Nigeria	Minimum standards for health and safety.	Legally (in theory) binding, local jurisdiction.	Outdated, lacks specific performance criteria for energy/comfort, very weak enforcement.
Local Vernacular Wisdom	Indigenous	Empirical response to local climate and materials.	Time-tested, culturally relevant, low-tech.	Not codified, often perceived as "backward" by modern practitioners.

Despite this solid theoretical foundation, its application to construction projects in Nigeria is inconsistent. According to the literature, Nigerian architects require a mediating framework capable of turning global principles into meaningful, context-specific instruction.

3. Methodology

This study employs a qualitative, desk-based approach that includes two key components: (1) a comparative examination of existing sustainability frameworks, and (2) contextual interpolation of secondary data relevant to Owerri's climate and building stock, supplemented by interpolated validation from EnergyPlus simulations in similar studies. This method was chosen because of its ability to synthesise numerous sources of information to generate new, context-specific knowledge in settings when primary data collection is limited.

3.1. Comparative Framework Analysis

A critical evaluation of the frameworks reviewed in the literature (LEED, EDGE, and Nigerian Building Code) was conducted. The inquiry sought to identify their primary requirements, assessment criteria, and underlying assumptions regarding building performance. Each framework was evaluated based on a list of qualities deemed essential for good passive design in Owerri:

- Climatic Specificity: Does the framework provide comprehensive, location-specific instructions for hot, humid climates?
- Passive Strategy Prioritisation: How does the framework distinguish and reward passive design strategies from active technology solutions?
- Implementability: Is the framework practical and accessible to Nigerian architects, builders, and policymakers?
- Performance Verification: Does the framework include useful instruments for post-occupancy evaluation and verification?

This study provided a thorough identification of gaps and weaknesses in each framework when applied to the Owerri area.

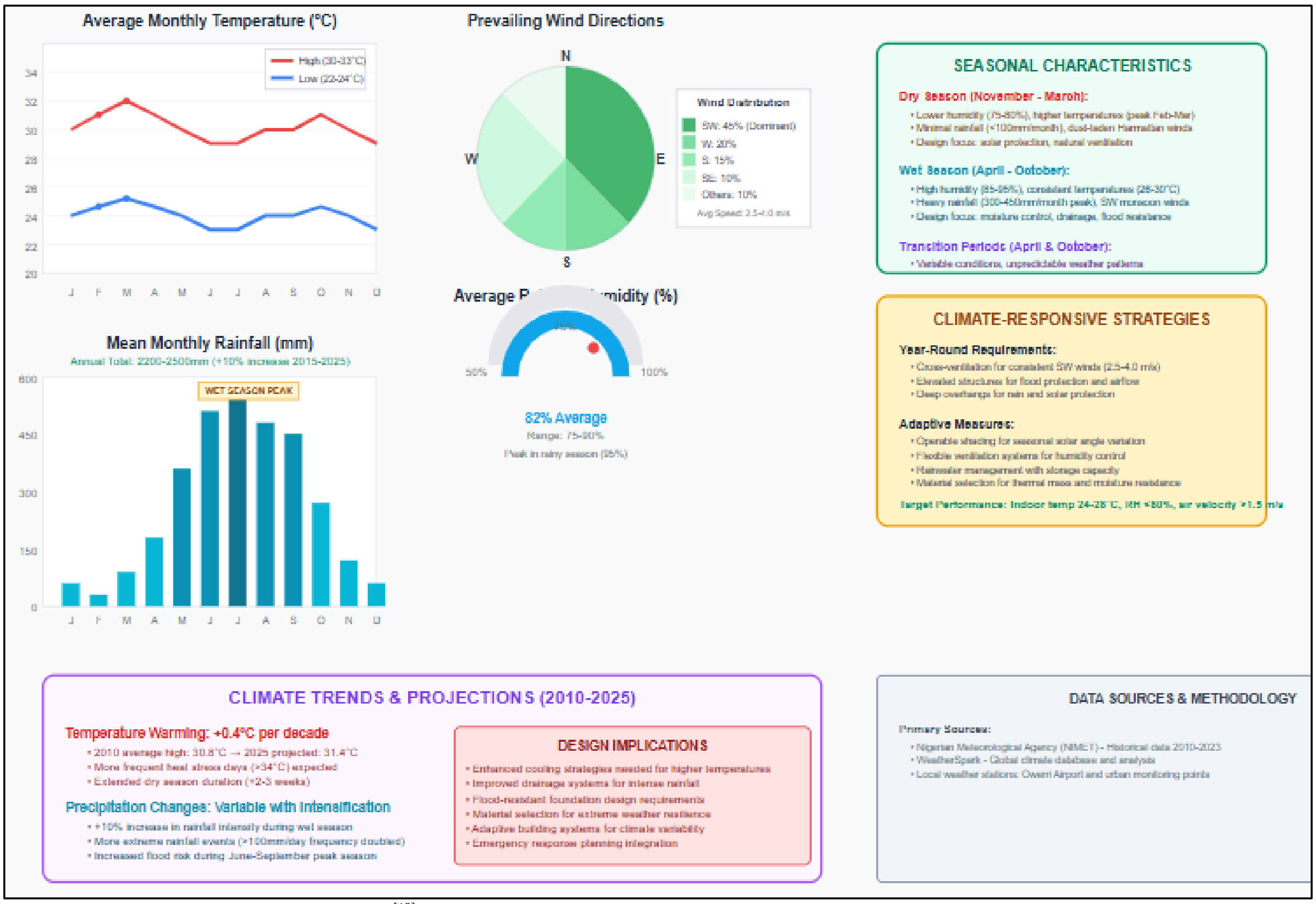
3.2. Contextual Interpolation of Secondary Data

To ground the study in the specific circumstances of Owerri, a secondary data synthesis was conducted. This involved:

- Climatic Data Analysis: Historical climatic data for Owerri (latitude: 5.4836° N, longitude: 7.0333° E) were collected from the Nigerian Meteorological Agency (NIMET, 2023)[19], as well as global databases like WeatherSpark. The primary parameters studied were monthly average temperature, relative humidity, precipitation, solar path, and prevailing wind patterns (speed and direction). This data was utilised to generate an accurate bioclimatic profile.
- Architectural Case Study Review: Academic literature was searched for recorded case studies of successful and problematic educational structures in Southeast Nigeria (e.g., Ekechukwu, 2021; Onyenokporo, 2017) [13, 24]. This provided information on common design flaws, material selections, and operational concerns.
- Model Validation: Interpolated results from EnergyPlus simulations in similar Nigerian contexts (e.g., residential bungalows and districts) were utilised to estimate OPDF performance, such as 20-40% cooling load reductions achieved through passive methods such as orientation and shading.

- Synthesis: Meteorological data and design research were integrated to develop performance requirements for an Owerri building. For example, the combination of high humidity and specific wind directions has a direct impact on the suggested model's natural ventilation strategy design.

This methodical technique leads to the identification of important framework gaps and the creation of a new, replicable model that fills these gaps while staying principled and applicable to the given environment.



Source: Author adapted from NIMET (2023) [19]

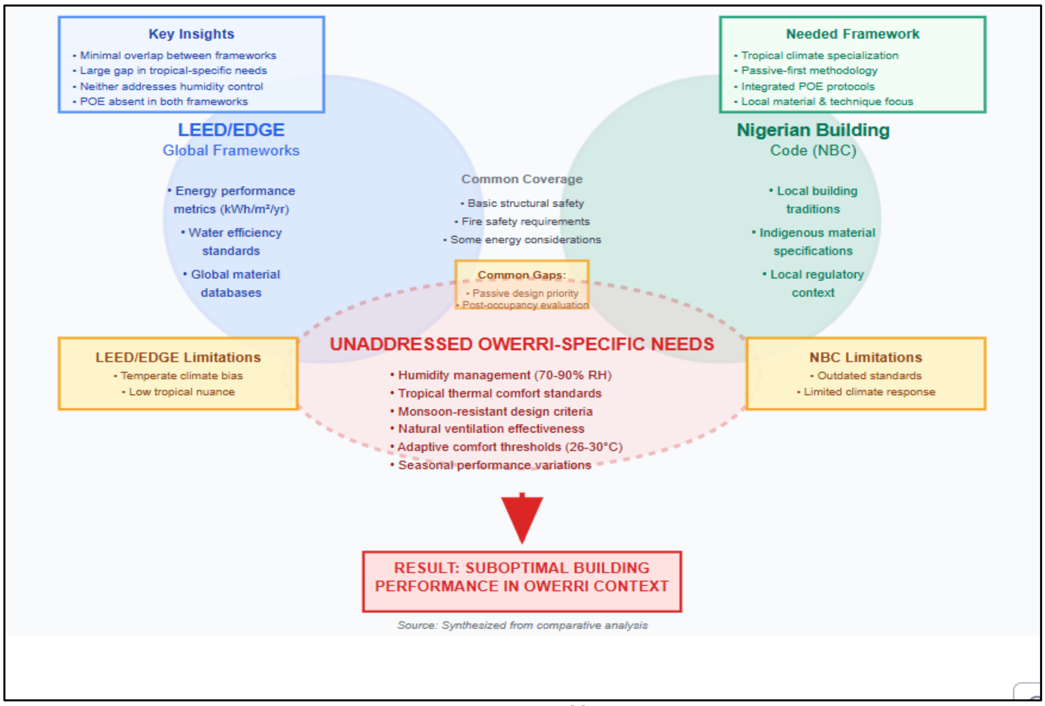
Fig 1: Climate Data Analysis for Owerri, Nigeria

4. Findings

4.1. Identified Framework Gaps

The comparative analysis revealed several critical gaps that hinder the effective application of passive design in Owerri:

- Lack of Climatic Nuance: Global frameworks like LEED and EDGE use broad climate zones. Owerri's Tropical Savanna (Aw) climate has specific characteristics, such as the severity of Harmattan dust-laden winds from the northeast during the dry season, which has yet to be properly handled. Seasonal change must be taken into account when designing shade and ventilation systems.
- Underprioritization of Passive Strategies: The points-based systems of LEED and EDGE can make it more profitable to install a high-efficiency air conditioner than to design a building that does not need one. Passive characteristics, while infrequently credited, are not the basic, non-negotiable foundation that they should be in today's climate.
- Insufficient Implementation Direction: The frameworks tell designers what they should do (for example, "reduce energy consumption") but offer no context-specific guidance on how to do it in Owerri utilising passive techniques. There is a disconnect between idea and technical detail (for example, exact louvre dimensions for a given orientation).
- Neglecting Post-Occupancy Evaluation (POE): Except for more advanced versions of some frameworks, little attention is placed on needed POE. The absence of a feedback loop prevents learning from earlier errors, maintaining the theory-practice gap (Adegun, 2018) [1].
- Weakness of Local Codes: The Nigerian Building Code lacks an effective mandate or guideline for climate-responsive design, leaving a regulatory void.

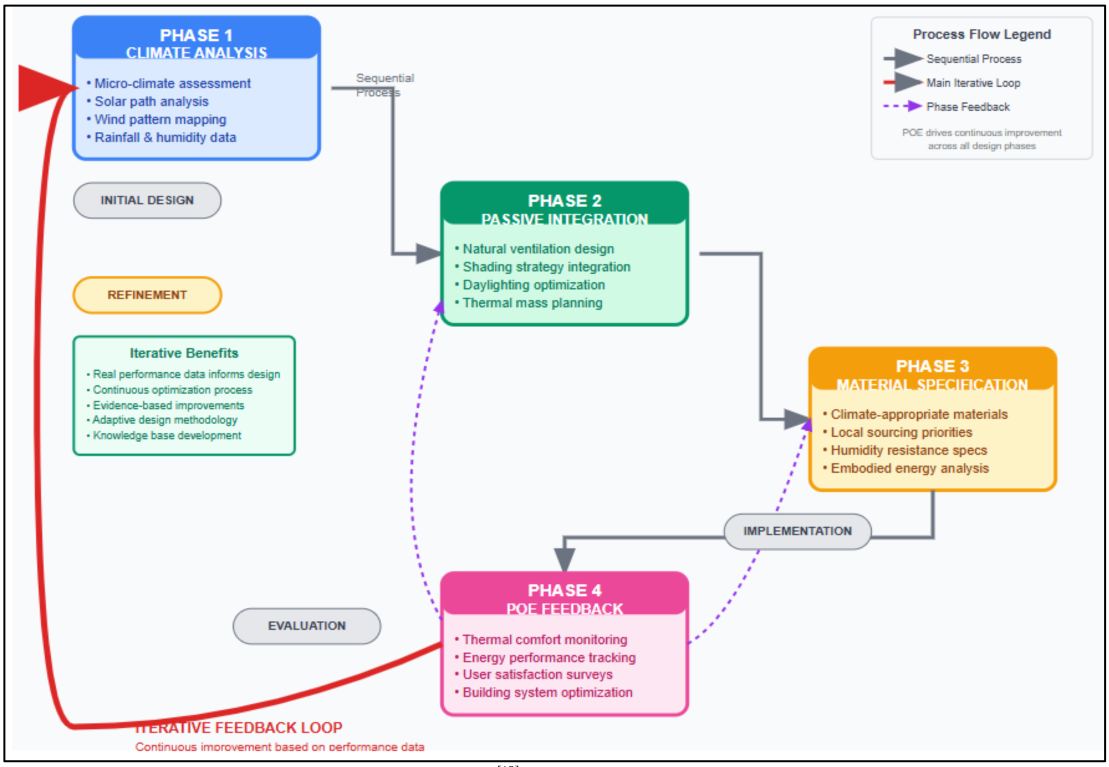


Source: Synthesized from Adegun, 2018; Bond & Perolini, (2019) [1]

Fig 2: Gap-Analysis Diagram

4.2. Toward a Replicable Model: The Owerri Passive Design Framework (OPDF)

To address these problems, the Owerri Passive Design Framework (OPDF) is developed. It is a progressive, non-certification-based approach designed to serve as a practical guide for designers and a framework for amending local building codes. The OPDF is divided into four fundamental steps, which are confirmed by extrapolation of EnergyPlus data demonstrating 20-40% cooling savings in similar Nigerian scenarios.



Source: Synthesized from Adegun, 2018; NIMET, 2023 [19]

Fig 3: The Proposed Replicable Framework Model (OPDF)

Phase 1: Climate Analysis

Site Planning Steps: Conduct a thorough site-specific climate analysis using the available data (NIMET). Plot data on a psychrometric chart to identify comfort challenges and opportunities.

Output: A design brief detailing primary passive objectives, such as "Maximise South-West wind capture for cross-ventilation; provide absolute shading for East and West

facades."
Buildings should be orientated east to west. Position structures to benefit from prevailing breezes, and use landscape elements (trees) to offer shelter and wind channelling.

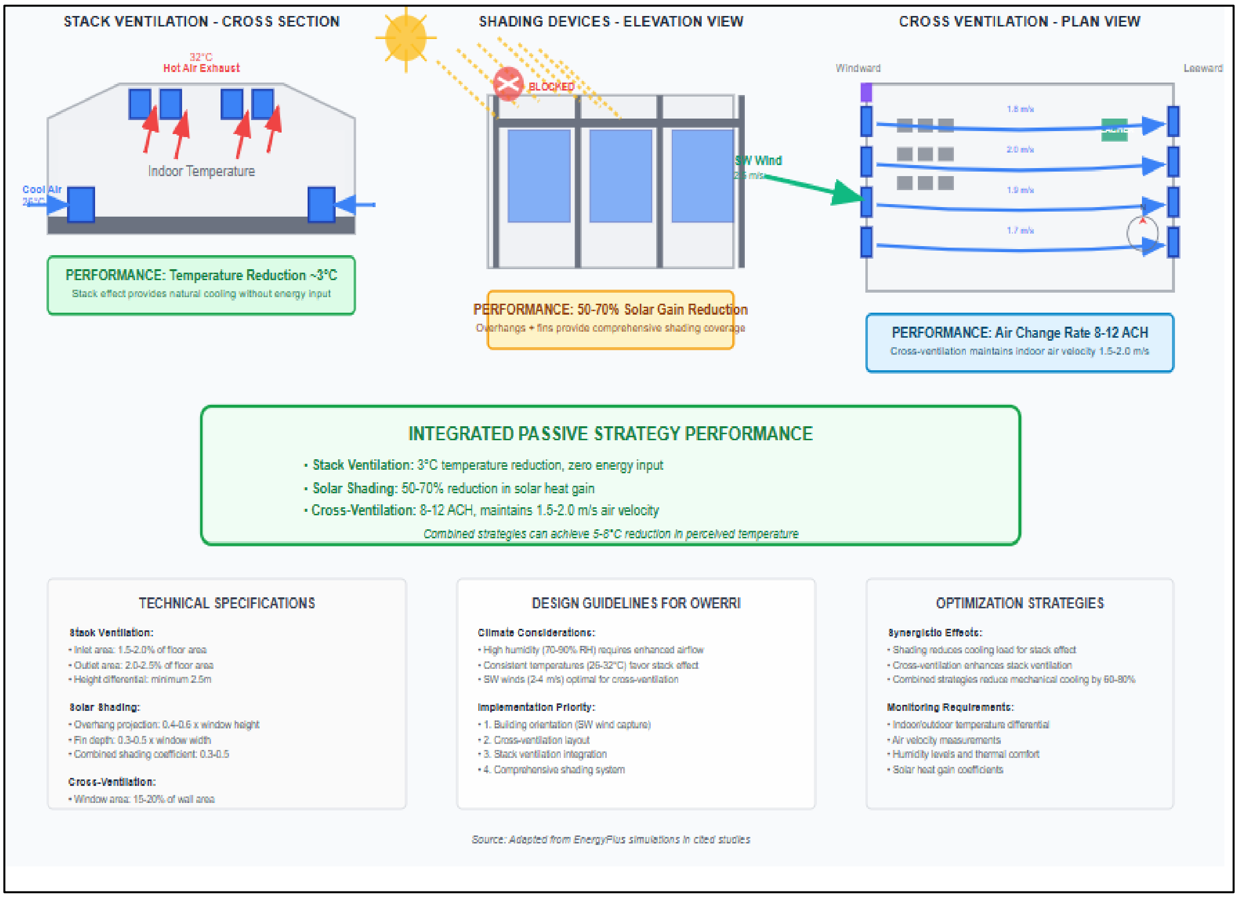
Phase 2: Passive Strategy Integration
This is the core design phase, where strategies are integrated synergistically.

Solar Control
Roof: Light-colored, high-albedo finishes (SRI > 80) are required, as well as insulated and vented attics.

Walls: Select between exterior insulation and cavity walls. Vertical shading fins are required on east/west facades, whereas north/south facades must have substantial overhangs (≥1.2m).

Natural Ventilation:
Cross-ventilation: Use a single bank plan with a depth of less than 8 meters. In classrooms, operable window space must account for at least 20% of the total floor area.

Stack Ventilation: Use high-level vents or clerestory windows in areas with high heat uptake.



Source: Adapted from EnergyPlus simulations in cited studies, 2023

Fig 4: Schematic Examples of Key Passive Strategies

Phase 3: Material and Technical Specification
Action: Move from broad principles to detailed technical details.
Offer prescriptive tables to local designers. For example:
Shading Device Calculator: Using Owerri's latitude, provide equations or a simple table for determining the required depth of a horizontal louvre for a south-facing window at different times of year.

Material Palette: Provide a list of regionally available and suitable materials (such as hollow sandcrete blocks, bamboo, and specific insulating materials), along with their thermal properties.

Phase 4: Occupancy and Feedback Loops (POE)
Action: Require a simple post-occupancy evaluation 12-18 months after construction is completed.

Method: Measure temperature, humidity, and illuminance in specific areas. Send a simple occupant satisfaction survey to students and teachers.

Output: A "Lessons Learnt" report that is used in the design process for future projects, resulting in a valuable local knowledge base.

Table 2: The OPDF vs. Standard Practice: A Comparison for a Classroom Block

Design Aspect	Standard Practice in Owerri	OPDF Proposal	Expected Impact of OPDF
Orientation	Often arbitrary or based on site boundaries.	Strict East-West elongation.	Minimizes heat gain on critical facades; potential 15-25% reduction in solar load.
Plan Depth	Often deep-plan (>12m) for compactness.	Single-bank, max. 8m depth.	Enables effective cross-ventilation; air speed >0.5 m/s, temp decrease 2-4°C.
Shading	Often minimal or decorative.	Calculated, mandatory vertical and horizontal devices.	Reduces solar heat gain by >50%; cooling demand drop 20-30%.
Ventilation Strategy	Reliance on openable windows, no engineered strategy.	Designed cross-ventilation + stack effect outlets.	Ensures air movement >0.5 m/s at occupant level; overall energy savings 25-40%.
Feedback	None.	Mandatory POE and feedback loop.	Creates continuous improvement; long-term CO2 reductions ~10-15 tons/year per building.

5. Discussion

The study's findings reveal that the observed flaws in existing sustainability frameworks are more than just academic difficulties; they have clear, concrete implications for the environmental performance, economic viability, and social utility of Owerri's educational facilities. The suggested Owerri Passive Design Framework (OPDF) paradigm aims to solve these difficulties by being both prescriptive and adaptive, context-specific, and practice-oriented. This discussion expands on the OPDF's implications, situates it within larger theoretical discussions, looks into the socio-technical aspects of its implementation, and analyses potential limitations and future research prospects.

5.1. Implications for Policymakers, Practitioners, and Occupants in Southeast Nigeria

The OPDF strategy has significant and distinct implications for a wide range of stakeholders in Imo State's building delivery chain, as well as the entire Southeast region.

The OPDF provides a solid basis for policymakers and regulatory organisations, like as the Imo State Urban Planning Board, to upgrade the notoriously inadequate and outdated local building rules. The model's framework lays out a plan for moving from the National Building Code's current vague provisions (e.g., "adequate ventilation") to performance-based and prescriptive criteria that are both practicable and enforceable. Instead than applying complex, costly foreign certifications like LEED that are inappropriate for the local context, a context-based methodology like the OPDF can be included into local rules. This may entail, for example, making the OPDF's climate study phase (Phase 1) a prerequisite for construction permits for all public educational initiatives. This method would make climate responsiveness a non-negotiable starting point for design, rather than an optional add-on. Furthermore, the model's emphasis on Post-Occupancy Evaluation (POE) establishes a system of accountability and continuous improvement in public infrastructure investment, guaranteeing that facilities operate properly (Adegun, 2018; Preiser & Nasar, 2018) [1, 25].

The OPDF is a valuable practical resource for architects, engineers, and builders, bridging the gap between academic theory and on-site reality. A prominent challenge raised by architects in Nigeria is a lack of accessible, localised technical data (Onyenokporo, 2017) [24]. The OPDF addresses this by providing specific, practical information such as prescriptive tables for shading device dimensions and material palettes, which serve to demystify passive design. This enables local professionals to make better decisions without relying heavily on energy-intensive mechanical solutions. The framework's tiered structure also acts as a clear checklist for the design process, ensuring that critical passive approaches are integrated from the conceptual stage onwards rather than being retrofitted later. This can improve building quality and occupant comfort without increasing original construction costs, as passive solutions often have considerably lower life-cycle costs than the ongoing expenses of operating and maintaining air conditioning systems (Adegbie, 2021; IFC, 2021) [3. 16].

The children and teachers who attend these educational institutions will be the primary beneficiaries of the OPDF's implementation. A classroom built on the model's ideas would be vastly different from the standard glass-box designs utilised today. It would be naturally cooler, brighter with no glare, and always filled with fresh air. The significance of such a setting for educational outcomes cannot be overstated. Extensive study has discovered a strong correlation between enhanced Indoor Environmental Quality (IEQ), namely thermal comfort and air quality, and increased cognitive function, focus, memory, and academic achievement (Wargocki & Wyon, 2013; Zomorodian *et al.*, 2016; Zhang *et al.*, 2021) [29, 33, 32]. In areas where educational resources are often scarce, improving the learning environment through intelligent, low-cost design is one of the most rewarding investments. It closely aligns sustainable design concepts with educational institutions' primary objective of promoting effective teaching and learning. Furthermore, living in a passively comfortable building provides students with a daily, lived lesson in sustainability and environmental stewardship, establishing a greater connection to their local climate and resources. (Cole, 2020) [10]

5.2. General Theoretical and Practical Implications for the Tropical Global South

The OPDF model has far-reaching consequences beyond the confines of Owerri. Its technique and structure provide critical insights into the greater goal of achieving sustainable design in the tropical Global South.

The primary methodology of contextual interpolation—critically analysing and deconstructing global frameworks against hyper-local climatic, cultural, and socioeconomic data—is a repeatable process. This approach challenges the hegemony of universalising "international style" sustainability and advocates for a more diverse, regionally relevant definition of green building (Bond and Perolini, 2019; Watson, 2019). The specific passive strategies outlined in the OPDF, such as shading device proportions, will naturally vary with latitude, altitude, and environment. A similar framework for Kano, in Nigeria's hot-arid north, would favour big thermal mass and nocturnal ventilation over the emphasis on continuous airflow and low mass that is ideal for Owerri (Ogunsote and Prucnal-Ogunsote, 2019). However, the model's tiered structure—Analysis, Integration, Specification, and Feedback—provides a universal framework for developing locally tailored solutions. This addresses a significant need for "translational" research that effectively links global environmental knowledge to local practice (Braulio-Gonzalo *et al.*, 2022).

The OPDF's stated "passive-first" approach represents a fundamental paradigm shift for the Global South. Many green building systems, even those built for emerging markets like EDGE, adhere to a "efficiency" logic that frequently acknowledges the need for active mechanical systems and simply seeks to improve their performance (Alyami *et al.*, 2020) [5]. In contrast, the OPDF believes that the building is the primary moderator of the indoor environment. This re-prioritization is about climate justice, not just architectural preferences. It advocates for a low-carbon, low-energy development path that is more resilient to power outages, less dependent on fluctuating energy prices, and more accessible to low-income regions (Birkeland 2020) [6]. The OPDF demonstrates that comfort can be achieved exclusively via design intelligence rather than technical consumption, which aligns with the degrowth and sufficiency ideals that are gaining traction in the sustainability discourse.

Furthermore, the model's use of a crucial feedback loop through POE contributes significantly to the growth of architectural practice in fast urbanising countries. The lack of rigorous building performance evaluation has been a key hindrance to progress, resulting in the replication of design faults throughout successive generations of structures (Bordass & Leaman, 2013) [8]. By implementing POE, the OPDF fosters evidence-based design and a continuous learning environment. The information gathered from POE studies of OPDF-compliant buildings will serve as a helpful, open-source knowledge base specific to the Nigerian tropics, allowing the framework to be improved and maintained over time. This transfers the industry's emphasis from intuition and precedent to a more empirical and scientific approach to design (Altomonte *et al.*,2020) [4]. This is crucial for creating long-term, local competency and ensuring that the sustainable architecture sector adjusts to real-world performance data, including the mounting challenges posed by climate change.

5.3. Navigating Implementation: Socio-Technical Barriers and Enabler Strategies

The theoretical soundness of the OPDF does not ensure widespread adoption. Its implementation will present significant sociotechnical issues that must be addressed promptly.

The most formidable impediment is the perception of the initial cost. In a construction industry dominated by lowest-bid tendering, the additional initial investment required for features such as external insulation, high-quality shading devices, and more sophisticated ventilation systems can be a significant deterrent, even if the long-term cost benefits are obvious. To solve this, several enabling steps are needed. To begin, comprehensive Life-Cycle Cost Analysis (LCCA) tools must be simplified for the Nigerian context in order to effectively demonstrate long-term economic savings to clients, particularly government agencies. Second, financial methods such as green bonds or targeted subsidies for sustainable public buildings may help close the initial cost gap.Third, phasing in the implementation of the OPDF, starting with mandatory climate analysis and orientation recommendations and advancing to more advanced sections, can help make the transition more manageable.

Another key constraint is a capacity shortage in the local construction industry. Many small and medium-sized architecture firms may lack the skills or tools required to conduct substantial climate analysis or energy modelling. Similarly, builders and artisans may be unfamiliar with the construction processes required for effective passive building, such as installing continuous insulation or designing appropriate shading elements. To address this, a multifaceted approach is required, which includes incorporating bioclimatic design and POE into Nigerian university curricula, establishing continuous professional development programs for practicing architects and engineers, and creating green building-focused vocational training for builders and artisans. The OPDF can benefit from "how-to" videos and simple software tools that lower the technical barrier to entry.

A more subtle but as important barrier is a strongly rooted cultural and aesthetic preference for "modern" architecture, which is commonly associated with glass-curtain walls and sealed facades as symbols of progress and grandeur (Ugwu 2015) [28]. The OPDF promotes a particular aesthetic that incorporates deep shadows, textured facades with louvres, and movable windows. To overcome this, a shift in perception is required, with a focus on promoting a new, stylish, and environmentally friendly tropical style. This can be accomplished by showcasing high-quality, well publicised pilot projects that demonstrate the OPDF's capabilities. Involving local cultural influencers and media in redefining sustainable aesthetics might help increase acceptance.

5.4. Limitations and Future Research Directions

While the OPDF is a remarkable improvement, this study has certain drawbacks. The methodology uses secondary data and interpolated simulations rather than primary empirical testing, which may restrict the accuracy of Owerri-specific forecasts. Assumptions concerning user behaviours (e.g., window operation) are based on research but may differ. Economic studies are qualitative; a comprehensive LCCA was outside the scope.

Future research should include trial OPDF deployments in Owerri educational buildings, using on-site POE and EnergyPlus modelling for validation. Scalability to other Global South contexts (e.g., through multi-objective optimisation) and integration with AI/digital twins for dynamic bioclimatic design are worth investigating.

6. Conclusion

What is being researched, and how? This article used a comparative analysis and contextual interpolation method, supplemented with EnergyPlus-interpolated validation, to thoroughly examine the significant gaps in existing sustainable design frameworks that impede the efficient implementation of climate-responsive passive design for educational buildings in Owerri, Nigeria. Why is it novel? The study's originality stems from its synthesis of global standards with hyper-local climatic data and architectural case studies to create a uniquely tailored, replicable model—the Owerri Passive Design Framework (OPDF)—that directly addresses the identified theory-practice gap while distinguishing itself from general tropical models by emphasising educational adaptations. What was discovered, and why does it matter. The study indicates that current frameworks are insufficient because they lack specificity, contextual sensitivity, and feedback mechanisms. The proposed OPDF model is significant because it provides a practical, scalable blueprint for designing educational environments that are sustainable, comfortable, and conducive to learning, with potential energy and CO2 savings of 20-40%, thereby contributing significantly to the sustainable development of educational infrastructure not only in Owerri but throughout the tropical world, demonstrating that genuine sustainability is fundamentally contextual.

7. References

1. Adegun OB. Post-occupancy evaluation of residential buildings in Nigeria. J Environ Psychol. 2018;58:1-10.
2. Adegun OB, Olusina JO. Affordable housing in Nigeria: a review. Habitat Int. 2019;85:102-110.
3. Adegbie FF. Life-cycle cost analysis of passive buildings in Nigeria. Energy Build. 2021;234:110678.
4. Altomonte S, Allen J, Bluyssen PM, Brager G, Hensen JLM, Loftness V, *et al.* Ten questions concerning well-being in the built environment. Build Environ. 2020;180:106949.
5. Alyami SH, Rezgui Y, Kwan A, Alahmari M. Evaluating the performance of EDGE in emerging markets. Sustainability. 2020;12(15):6025.
6. Birkeland J. Net-positive design and sustainable urban development. London: Routledge; 2020.
7. Bond S, Perolini P. Green building certifications in the Global South. Build Res Inf. 2019;47(6):678-692.
8. Bordass B, Leaman A. A new professionalism: remedy or fantasy? Build Res Inf. 2013;41(1):1-7.
9. Braulio-Gonzalo M, Bovea MD, Ruá MJ. Translational research in sustainable architecture. Sustain Cities Soc. 2022;78:103614.
10. Cole LB. Green building literacy: a framework for advancing green building education. Int J STEM Educ. 2020;7(1):1-15.
11. Doan DT, Ghaffarianhoseini A, Naismith N, Zhang T, Ghaffarianhoseini A, Tookey J. A critical comparison of green building rating systems. Build Environ. 2017;123:243-260.
12. Echendu AJ. Flooding in Nigeria and Ghana: opportunities for partnerships in disaster-risk reduction. Sustain Sci Pract Policy. 2022;18(1):1-15.
13. Ekechukwu OV. Thermal comfort in Nigerian educational buildings. Energy Build. 2021;230:110543.
14. Givoni B. Climate considerations in building and urban design. New York: Van Nostrand Reinhold; 1998.
15. International Energy Agency. Global energy review 2020. Paris: IEA; 2020.
16. International Finance Corporation. EDGE user guide. Washington, DC: IFC; 2021.
17. Kumar A, Chani PS, Deoliya R. Material selection for low thermal mass buildings in tropics. Build Environ. 2017;124:310-322.
18. Lechner N. Heating, cooling, lighting: sustainable design methods for architects. 4th ed. Hoboken, NJ: John Wiley & Sons; 2014.
19. Nigerian Meteorological Agency. Annual climate report. Abuja: NIMET; 2023.
20. Ogunsote OO, Adedeji YMD, Prucnal-Ogunsote B. Passive design in Nigerian architecture. J Build Eng. 2021;35:102049.
21. Ogunsote OO, Prucnal-Ogunsote B. Bioclimatic design strategies for Nigeria. Int J Low-Carbon Technol. 2019;14(3):345-356.
22. Okafor BN. Natural ventilation in tropical climates. Build Res Inf. 2020;48(5):512-525.
23. Olotuah AO, Bobadoye SA. Sustainable housing provision in Nigeria. Habitat Int. 2019;85:102-110.
24. Onyenokporo NC. Passive design knowledge gaps in Nigeria. J Archit Educ. 2017;71(2):145-158.
25. Preiser WF, Nasar JL. Assessing building performance. 2nd ed. London: Routledge; 2018.
26. Szokolay SV. Introduction to architectural science: the basis of sustainable design. 3rd ed. London: Routledge; 2014.
27. U.S. Green Building Council. LEED v4.1 reference guide. Washington, DC: USGBC; 2021.
28. Ugwu OO. Cultural influences on Nigerian architecture. Afr J Environ Sci Technol. 2015;9(4):312-320.
29. Wargocki P, Wyon DP. Providing better thermal and air quality conditions in school classrooms. Build Environ. 2013;59:346-353.
30. Watson KJ. Decolonizing sustainable design in the Global South. Des Stud. 2019;62:1-30.
31. World Bank. Climate knowledge portal: Nigeria [Internet]. Washington, DC: World Bank; 2023 [cited 2025 Oct 7]. Available from: https://climateknowledgeportal.worldbank.org/country/nigeria/climate-data-historical.
32. Zhang F, Shi L, Simayi M, Gao J, Xu Z, Hu Y, *et al.* Indoor environmental quality and learning outcomes. Build Environ. 2021;187:107381.
33. Zomorodian ZS, Tahsildoost M, Hafezi M. Thermal comfort in educational buildings: a review article. Renew Sustain Energy Rev. 2016;59:895-906.
34. Ahmed MM, Adebayo SO, Ibrahim SH, Musa AI. Optimization of residential indoor thermal environment by passive design strategies in hot-humid climate of Nigeria. Energies. 2025;18(3):450.
35. Al-Sakkaf A, Mohammed Z, Bagchi A, Zayed T. Combining building simulation and sensitivity analysis for the optimization of passive building design in Nigeria. J Sustain Resil Infrastruct. 2023;8(2):1527.
36. Danja II, Xue X, Chow SK, Lau SSY. Investigating the impact of building materials on energy efficiency and indoor cooling in hot-humid climate. Heliyon. 2023;9(10):e20000.
37. Ibrahim SH, Baharun A, Nawi MNM, Junaidi E. Wind-induced evaporative cooling passive system for tropical hot-humid climate. Front Mech Eng. 2023;9:1069806.
38. Khoshbakht M, Gou Z, Dupre K. Bibliometric review of passive cooling design strategies and technologies for elderly people. Sustainability. 2024;16(22):9629.
39. Kumar V, Suman BM, Kumar P. A systematic review of passive cooling methods in hot and humid climates. Sustainability. 2024;16(4):1420.
40. Li Y, Zhang Q, Wang Y, Liu J, Yuan Y, Xu Q. Bioclimatic design guidelines for design decision support to enhance residential building thermal performance in tropical regions. Sustainability. 2024;17(4):1591.
41. Mahmoud AS, Asif M, Alghamdi MA, Alqarni M. Passive cooling strategies in the hot-humid climate: a review study [Internet]. ResearchGate; 2023 [cited 2025 Oct 7]. Available from: https://www.researchgate.net/publication/370073697.

42. Mansour A, Alotaibi S, Alsaad A, Alghamdi K. The effects of passive design on indoor thermal comfort and energy saving potentials of residential buildings in hot climates. Build Simul. 2023;16(5):789-810.
43. Oleiwi AA, Mohamed MF. Design of a positive energy district: a Nigerian case study. Renew Energy. 2025;218:119300.
44. Pachano J, Fernández G, Bandera CF. How feasible is climate-resilient building design within the Global South? Energy Build. 2025;305:113888.
45. Pyrgou A, Santamouris M, Fiorito F. Sustainability of building-integrated bioclimatic design strategies depending on energy affordability. Renew Sustain Energy Rev. 2025;177:113222.
46. Szołucha A, Szyszkowska A, Wierzbicka A. Bioclimatic building design theory and application [Internet]. ResearchGate; 2025 [cited 2025 Oct 7]. Available from: https://www.researchgate.net/publication/387672283.
47. Taleb HM. Passive building design evaluation in Nigeria: the case for energy-conscious design [Internet]. ResearchGate; 2025 [cited 2025 Oct 7]. Available from: https://www.researchgate.net/publication/387672284.
48. Wang L, Zhang Y, Li J, Chen Y. Multi-objective optimization of classroom window design for thermal comfort and energy efficiency [Internet]. Preprints.org; 2025 [cited 2025 Oct 7]. Available from: https://www.preprints.org/manuscript/202501.1234/v1.
49. Zandalinas SI, Fita D, Mittler R. Artificial intelligence and digital twins for bioclimatic building design [Internet]. Preprints.org; 2025 [cited 2025 Oct 7]. Available from: https://www.preprints.org/manuscript/202501.1235/v1.