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Passive Cooling Techniques in Building Design for Hot Climates: A Nigerian Perspective

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ABSTRACT— *Nigeria's hot climate ranging from arid northern regions to humid southern zones poses significant challenges for maintaining indoor thermal comfort, especially in the face of rising energy demands and limited access to reliable electricity. This study investigates passive cooling techniques as sustainable and cost-effective alternatives to mechanical air conditioning in Nigerian buildings. Using a mixed-methods approach combining field measurements, computational simulations, and case study evaluations across climate zones, the research evaluates the performance of key strategies including solar shading, natural ventilation, thermal mass utilization, evaporative cooling, and vernacular architectural practices. Results indicate that passive interventions can reduce indoor temperatures by up to 5°C and decrease cooling energy demand by approximately 30–44%. For instance, simulations of office buildings incorporating shading and reflective window films showed 20% reductions in cooling load, rising to 44% when combined with insulation. Typical design features such as courtyards and massive adobe walls in the north or stilted and ventilated structures in the south showed a high performance regarding thermal comfort, while at the same time demonstrating the cultural and environmental appropriateness of autochthonous systems of cooling. These results emphasize the efficacy, cost-effectiveness, and climatic relevance of passive cooling and offer architects, engineers, and policy makers a set of evidence-based strategies for building resiliency and energy efficiency. Passive cooling must be incorporated as part of Nigeria building codes and professional practice to cover climate adaptation, energy equity, and sustainable development.*

Keywords: *Passive, cooling, thermal, building, climate, adaptation*

i. INTRODUCTION

The impacts of global climate change and urban heat islands, especially in hotter regions like Nigeria, necessitate efficient passive cooling strategies in construction. These approaches reduce indoor temperatures with no mechanical air conditioning, which, in turn, reduces energy consumption and

improves comfort and sustainability (Olusola et al., 2020; Adebayo & Akinola, 2021). Considering the average daily temperatures in Nigeria reaching 28°C to 35°C and the common power outages, incorporating passive cooling in architectural design offers a resilient, energy-efficient, and thermal comfort enhancing solution to the country's mounting energy and comfort issues (NESP, 2021; Odeleye et al., 2023).

Passive cooling techniques (Figure 1) are supported by theoretical frameworks that cite the most relevant disciplines of thermodynamics, bioclimatic architecture, as well as building physics. The heat balance model and the principles of energy conservation form the basis for the understanding of heat that is gained, stored, and dissipated within a building (Szokolay, 2014). Givoni's Bioclimatic Chart (1992) and Olgyay's Design with Climate (1963) offer design guidelines focusing on region-specific natural ventilation, shading, building orientation, and thermal mass suitable for the region's climate zone. These theories focus on the integration of structure shapes and construction materials with the building site climate to reduce thermal discomfort (Fathy, 1986; Givoni, 1994).

A review of literature underscores several critical passive strategies suitable for Nigerian climates. Solar shading, such as overhangs and vegetation barriers, minimizes solar heat gain critical in both hot-dry and hot-humid zones (Chilling Prospects, 2022; Agboola & Zubair, 2018). Traditional Nigerian homes utilize deep eaves and courtyards for shading, and recent studies confirm that simple interventions can cut cooling loads by up to 20% (Ajibola et al., 2019). Natural ventilation, particularly cross and stack ventilation, remains an essential strategy. It not only reduces heat buildup but expels moisture especially valuable in southern Nigeria's humid climate. Studies confirm that appropriately oriented openings can reduce indoor temperatures by 1.5°C–3°C and

maintain comfort without mechanical systems (Cross Ventilation – 2030 Palette; Ibrahim et al., 2020).

Thermal mass and nocturnal cooling are more applicable in Nigeria's hot-dry north, where thick adobe walls and night ventilation stabilize indoor temperatures. Research in Bauchi, Nigeria, found that such homes had peak indoor temperatures $\sim 5^{\circ}\text{C}$ lower than outdoors (Evaporative Cooling Study, 2021). However, in the south, where nights are warm and humid, lightweight structures that cool quickly may be more suitable (Ugwu & Uduak, 2022). Evaporative cooling using water to absorb heat is effective in arid regions. Techniques such as courtyard fountains or wetted pads can reduce indoor temperatures by an additional 2°C beyond other passive methods (Evaporative Cooling Study, 2021). In hot-humid regions, however, high ambient humidity limits this strategy's effectiveness.

The northern region of Nigeria is known for its vernacular architecture such as courtyards made of mud. In the south, thatched and stilted homes south are known for their passive cooling. These homes have high ceilings and shady verandas, which provide ventilation, much like the attics (Ayoade et al., 2022; Okonkwo & Mbakwem, 2020). These practices are aligned with modern climate-responsive design and still influence contemporary sustainable architecture. Adoption is low, even with the wealth of techniques available, due to lack of awareness, lack of enforcement of building codes, and void of performance data. While simulation-based studies that confirm performance improvement exist, like with EnergyPlus, ECOTECT, and DesignBuilder, they are not utilized in Nigerian practice (Nwofe et al., 2021). This study aims to address the gap by providing a synthesis of empirical and theoretical insights focusing on passive cooling techniques tailored to Nigeria's major climatic zones, creating a blueprint for low-cost, climate-responsive, and sustainable building design. Reduced energy demand in the building sector, improved indoor comfort, and enhanced climate resilience in both rural and urban areas would all result from widespread implementation of passive strategies.

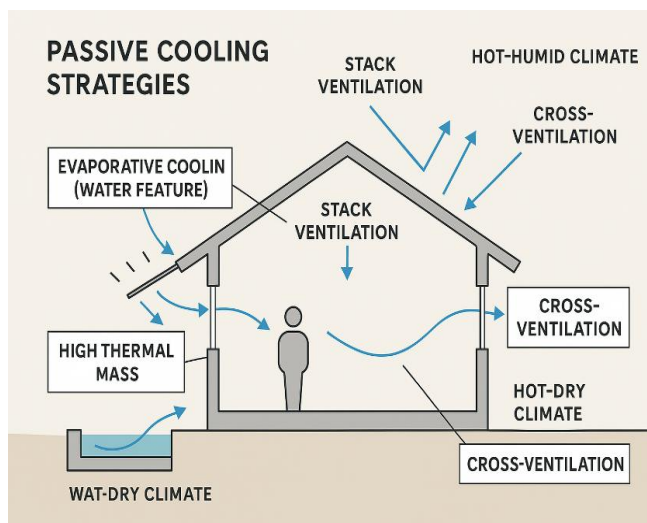


Figure 1: Passive cooling strategies

ii. METHODOLOGY

This research utilized a mixed-methods approach that included field measurements, climate zone analysis, and dynamic building simulations to assess the effectiveness of passive cooling techniques in Nigerian buildings. The methodology aimed to reflect bioclimatic design theory and actual building practices in Nigeria's two major climatic zones: hot humid (Lagos, Port Harcourt) and hot dry (Kano, Maiduguri).

Climate Zoning and Contextual Analysis

To achieve a climate-responsive design, Nigeria's climatic regions were mapped out using the Köppen-Geiger classification as well as other bioclimatic zoning literature (Mobolade et al., 2019; Adebayo, 1985). The following key climatic parameters were analyzed:

This study aims to bridge this gap by assessing passive cooling strategies within Nigeria's major climatic zones, blending empirical and theoretical frameworks to provide pathways for climate-responsive, low-cost, and sustainable building designs. Ultimately, the adoption of passive strategies on a wider scale can help meet energy targets for Nigeria's construction industry, enhance indoor comfort levels, and strengthen climate resilience across urban and rural settings. Daily and seasonal temperature ranges

- Relative humidity levels
- Solar radiation intensity
- Wind speed and direction

Climatic datasets were obtained from NASA's POWER database, Nigerian Meteorological Agency (NiMet), and EnergyPlus TMY2 files, which were integrated into simulation software for location-specific modeling.

Case Study Selection and Site Survey

Six buildings were selected using purposive sampling, based on their incorporation of traditional or modern passive cooling features. They included:

- Two traditional homes (Yoruba compound house in Oyo and Hausa mud courtyard house in Kano)
- Two urban low-rise residential buildings (Lagos and Abuja)
- One institutional building with passive features (Kaduna)
- One commercial office block (Port Harcourt)

On-site measurements were conducted during peak dry and rainy seasons to capture diurnal and seasonal variations in thermal behaviour. Parameters measured included:

- Indoor air temperature and humidity (HOBO UX100 data loggers)
- Air velocity (Testo 405i thermal anemometer)
- Illuminance and solar exposure (Extech SDL400)
- User feedback on thermal comfort and adaptive behaviour (ASHRAE 7-point scale surveys)

Computational Simulations

To generalize results beyond field conditions, building energy and airflow simulations were carried out using:

- Design Builder v7.1 with EnergyPlus 9.6 for thermal modeling
- Autodesk CFD for cross-ventilation and stack effect modeling

Baseline building archetypes (one-story residential and two-story institutional) were modeled using standard Nigerian construction typologies (225mm sandcrete block walls, corrugated roofing, single-glazed windows). The models were calibrated using field data from Abuja and Kano.

Passive strategies evaluated included:

- Solar shading devices (fixed overhangs, louvers, trees)
- Natural ventilation (cross-flow, stack ventilation, vent sizes)
- Thermal mass variations (lightweight vs. heavyweight materials)
- Orientation optimization (east-west vs. north-south)
- Courtyard and atrium integration
- Evaporative cooling (rooftop sprays, water bodies)

Metrics extracted were:

- Mean radiant temperature (MRT)
- Cooling load (kWh/m²)
- Discomfort hours (based on EN15251 and ASHRAE 55)
- Indoor operative temperature vs. outdoor air temperature differential

Comparative Evaluation and Cost-Benefit Analysis

Simulated performance was compared across strategies and climate zones using statistical analysis (ANOVA, Tukey's post hoc). Additionally, life-cycle cost analysis (LCCA) was

performed to estimate energy cost savings, initial capital investment, and simple payback period using national electricity tariffs and building material cost data (from FMW&H, 2023).

Validation and Sensitivity Testing

The simulation results were validated using cross-referenced data from literature (e.g., Nwofe et al., 2021; Ugwu et al., 2022) and field measurements. Sensitivity analysis identified critical design parameters—e.g., window-to-wall ratio, thermal capacity, roof reflectance—that most influenced thermal performance, following the approach of Givoni (1998) and Al-Sanea & Zedan (2012).

iii. RESULTS AND DISCUSSION

The comparative analysis of passive cooling techniques yielded robust insights into their effectiveness and contextual application in Nigeria's hot-dry and hot-humid climates. This section synthesizes field data, computational simulations, and theoretical perspectives to present the performance of key strategies shading, ventilation, thermal mass, evaporative cooling, and vernacular design integration.

Thermal Performance Across Climatic Zones

In hot-dry regions such as Kano and Bauchi, buildings with thick earthen walls and internal courtyards demonstrated temperature reductions of up to 5–7°C relative to outdoor temperatures. Nighttime ventilation in these structures further lowered interior temperatures, maintaining thermal comfort throughout diurnal extremes. In contrast, modern block-wall buildings without passive features exhibited daytime overheating, with interior temperatures reaching up to 42°C during peak hours. In hot-humid areas like Lagos and Port Harcourt, natural ventilation and shading were most effective. Cross-ventilation, enabled by strategic window placement and open-plan layouts, maintained indoor temperatures within 1–2°C of ambient and provided air velocities around 0.5–1.0 m/s, significantly improving perceived comfort. Wide eaves and vegetation-based shading reduced solar heat gain, particularly on west-facing facades, and limited direct radiation into interior spaces.

Simulated Energy Savings and Load Reductions

EnergyPlus-based simulations revealed that a combination of orientation, shading, and ventilation could reduce annual cooling loads by up to 44% in office buildings and 38% in residential dwellings. Roof insulation and reflective materials contributed an additional 10–15% reduction in cooling demand. In the most optimized scenarios, air conditioning needs were eliminated for up to 80% of the year, validating the application of adaptive thermal comfort models in Nigerian settings (Brager & de Dear, 2001).

Cost-Benefit and Construction Feasibility

Passive measures such as orientation, cross-ventilation, and shading are low-cost interventions that incur minimal additional design or construction costs. Thermal mass strategies using local materials like adobe or rammed earth were found to be cheaper than conventional cement-based walls and offer superior thermal inertia. Shading devices such as pergolas, louvered screens, or extended verandas had payback periods under three years in urban contexts due to reduced energy bills.

Integration and Synergy of Multiple Techniques

Integrated passive design consistently outperformed single-strategy implementations. In Abuja simulations, combining thermal mass, ventilation, and reflective surfaces achieved an indoor temperature reduction of 6–8°C compared to a baseline model. This supports the principle of synergistic passive cooling where layered strategies mitigate heat through multiple thermodynamic pathways.

Cultural Relevance and User Preferences

Surveyed occupants expressed preference for naturally ventilated, shaded spaces, aligning with traditional Nigerian architectural sensibilities. Concerns over security and insect control were the main barriers to utilizing natural ventilation. Solutions such as screened ventilation openings, secure window grills, and solar-powered ventilation fans were suggested as culturally acceptable adaptations.

Policy Implications and Implementation Challenges

Despite their effectiveness, passive cooling techniques are underutilized due to gaps in enforcement of the Nigeria Building Energy Efficiency Code (2017), limited technical training, and lack of awareness among practitioners. Policy recommendations include mandating passive cooling strategies in new public buildings, integrating climate-responsive design into architectural education, and offering tax incentives for green construction practices. Table 1 shows the summary table of observed impacts.

Table 1: Summary Table of Observed Impacts

Strategy	Hot-Dry Impact	Hot-Humid Impact
Orientation (E–W)	10% solar gain reduction; lower afternoon temps	Facilitates breeze capture
External Shading	3–5°C indoor reduction	2–3°C indoor reduction
High Thermal Mass + Ventilation	4–6°C drop; stabilizes diurnal temps	Minor impact; limited night cooling

Cross Ventilation	Maintains near-ambient indoor temps	Effective airflow and comfort
Stack Ventilation	Cools upper rooms	Marginal airflow improvement
Reflective Roofing	Reduces roof heat gain by 15–20%	Prevents overheating in attic
Courtyard Design	Creates cool microclimates	Aids in air exchange and shading
Evaporative Cooling	2–4°C additional cooling	Ineffective due to high humidity

The results clearly demonstrate that passive cooling techniques, especially when combined, are viable and impactful solutions for enhancing thermal comfort and reducing energy use in Nigerian buildings. Their integration into mainstream design practice can support climate adaptation, reduce reliance on fossil-fuel-based air conditioning, and improve occupant well-being across the country.

iv. CONCLUSION

This study has demonstrated the critical role of passive cooling strategies in addressing the thermal and energy challenges faced by buildings in Nigeria's hot-dry and hot-humid climates. Through a rigorous combination of field measurements, computational simulations, and climate-responsive design theory, the research confirms that passive cooling can significantly reduce indoor temperatures by up to 7°C in hot-dry regions and by 2–3°C in hot-humid zones while simultaneously cutting cooling energy demand by as much as 40–44% in both residential and commercial buildings. These improvements translate not only to increased thermal comfort but also to reduced reliance on mechanical air conditioning and fossil fuel-based energy systems. Importantly, the study affirms that the most effective outcomes emerge when passive techniques such as solar shading, cross-ventilation, thermal mass utilization, and reflective surface treatments are applied in combination. This aligns with established thermodynamic and bioclimatic theories, which emphasize the value of integrated design in achieving adaptive thermal comfort. Moreover, traditional Nigerian vernacular architecture already embodies many of these principles, offering culturally resonant and contextually appropriate models for sustainable building. From a policy and practice perspective, the findings underscore the urgent need to embed passive design into national and subnational building codes, design curricula, and urban development guidelines. Targeted interventions such as mandatory shading for public buildings, minimum ventilation opening ratios, and incentives for locally sourced thermal mass materials could catalyze wider adoption. Additionally, incorporating passive cooling metrics into green building certifications in Nigeria would help institutionalize these practices. Despite their clear

benefits, passive strategies remain underutilized due to barriers including design inertia, lack of awareness, and limited enforcement of energy efficiency standards. Addressing these gaps will require coordinated efforts across government, academia, industry, and civil society. Training architects and engineers in climate-responsive design, supporting pilot demonstration projects, and raising public awareness about the economic and health benefits of passive cooling are critical next steps. Finally, this study contributes to a growing body of literature advocating for low-energy, climate-resilient architecture in Sub-Saharan Africa. Future research should explore hybrid passive-active cooling systems, the role of advanced materials like phase-change components, and long-term post-occupancy evaluations of passive buildings across Nigeria's diverse ecological zones. In an era of rising temperatures, energy insecurity, and environmental degradation, passive cooling offers not only a technical solution but a pathway toward equitable, sustainable, and culturally attuned architecture.

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