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Reviewing the Application of Passive Cooling Techniques in the Design of Faculty of Environmental Sciences, Gombe State University, Nigeria

[1]Ishaq, Adamu, [2]Abbas Said El-Nafaty, [3]I. U. Hussaini, [4]Sarkile Abubakar, [5]M. M. Bello& [6]Usman Muhammad Bashir
[1,2,3,4,5&6]Department of Architecture,
Abubakar Tafawa Balewa University, Bauchi, Nigeria.

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Abstract

This study examines the application of passive cooling techniques in the design of the Faculty of Environmental Sciences at Gombe State University (GSU), Nigeria, to address the challenges posed by the region's hot, dry climate and unreliable electricity supply. Using a mixed-method approach—combining case study analysis, climatic data review, and dynamic simulation—the research evaluates strategies such as shading devices, increased thermal mass, natural ventilation, and reflective materials. Results demonstrate that these techniques significantly reduce indoor temperatures and cooling loads, thereby improving thermal comfort and reducing dependence on mechanical cooling systems. The findings advocate for the mainstream adoption of passive cooling in educational buildings across Nigeria, highlighting its potential for energy efficiency, environmental sustainability, and cost reduction. The study underscores the importance of climate-responsive design in institutional architecture, especially in regions with harsh climates and limited energy resources. By integrating passive cooling strategies, universities can create conducive learning environments while minimizing operational costs and environmental impacts.

Keywords*: Passive cooling, Thermal comfort, Energy efficiency, Sustainable design, Educational buildings*

Corresponding Author: **Ishaq, Adamu**

Background to the Study

Nigeria's tropical climate, characterized by high temperatures and solar radiation, poses significant challenges to indoor thermal comfort and energy consumption in buildings. The Faculty of Environmental Sciences at Gombe State University exemplifies the need for climate-responsive design to mitigate excessive cooling demands and promote sustainability. Passive cooling techniques, which utilize natural processes to regulate indoor temperatures without mechanical energy input, offer viable solutions to these challenges (Hu et al., 2023; Akaainjo & Abdullahi, 2018). This paper explores the integration of such techniques in the faculty's design, aiming to enhance occupant comfort and reduce environmental impact. Passive cooling techniques are crucial for enhancing thermal comfort and reducing energy consumption in buildings, particularly in tropical regions like Nigeria. These techniques utilize natural methods to maintain comfortable indoor temperatures without mechanical cooling (Ismail et al., 2018). Studies have shown that passive design strategies can significantly decrease cooling loads and improve energy efficiency in residential and office buildings (Inusa & Alibaba, 2017; Muhammad Usman Kanoma et al., 2021). Common passive cooling approaches include climate-responsive design, natural ventilation, shading, and thermal mass (Kamal, 2012). However, research indicates that the implementation of these techniques in Nigerian university buildings is often inadequate, with some structures scoring below 50% in passive cooling assessments (Muhammad Usman Kanoma et al., 2021). Adopting passive cooling strategies is essential for mitigating climate change impacts, reducing energy demand, and creating more comfortable and environmentally conscious buildings in tropical climates (Ismail et al., 2018; Inusa & Alibaba, 2017).

Literature Review

Passive cooling strategies have become central to sustainable architectural design, particularly in hot and dry climates such as that of Gombe, Nigeria. These strategies aim to reduce indoor temperatures and energy consumption by harnessing natural environmental forces without relying on mechanical cooling systems. Recent studies from 2020 to 2025 have advanced the understanding and application of passive cooling techniques, demonstrating their effectiveness in improving thermal comfort and reducing energy demand in buildings.

Effectiveness of passive cooling techniques by Hu et al. (2023) conducted a comprehensive review of passive design approaches in hot climates, finding that such strategies can reduce indoor temperatures by an average of 2.2°C, decrease cooling loads by approximately 31%, and save up to 29% in energy consumption. Their analysis highlights key passive cooling techniques including shading devices, thermal mass utilization, natural ventilation, and reflective surfaces. These strategies work synergistically to minimize heat gain during the day and promote heat dissipation during cooler periods, thereby stabilizing indoor thermal conditions.

Similarly, Alawadhi et al. (2021) studied the impact of shading and natural ventilation on thermal comfort in residential buildings in arid regions. Their findings confirmed that external shading devices, such as overhangs and louvers, significantly reduce solar heat gain, while cross-ventilation enhances convective cooling, leading to improved occupant comfort without mechanical cooling. This aligns with the findings of Hu et al. (2023), reinforcing the importance of combined passive strategies.

Passive cooling within the Nigerian context, by Akaainjo and Abdullahi (2018) demonstrated through simulation that double-skinned façades and shading devices can reduce cooling loads by up to 35% in ICT buildings located in hot and dry climates. Their study emphasized the role of façade design in controlling solar radiation and facilitating natural ventilation, which are critical in tropical environments. Building on this, Usman et al. (2022) investigated passive cooling potentials in office buildings in northern Nigeria, reporting that optimized building orientation and fenestration design could reduce indoor temperatures by 3°C and cut cooling energy demand by 30%, highlighting the relevance of climate-responsive design.

Ismail et al. (2018) underscored the importance of material selection and building orientation in tropical climates. Their research showed that using locally available materials with high thermal mass, such as stabilized earth blocks, helps moderate indoor temperature fluctuations by absorbing heat during the day and releasing it at night. This principle has been widely adopted in vernacular architecture and is increasingly integrated into modern sustainable designs (Adekunle & Ojo, 2021).

Recent advances in passive cooling research technologies and design approaches have focused on integrating traditional techniques with modern technologies. For example, Bello et al. (2023) explored the use of phase change materials (PCMs) embedded in building envelopes to enhance thermal mass effects in hot climates. Their experimental study showed that PCMs could reduce peak indoor temperatures by 2.5°C and extend thermal comfort periods, offering a promising complement to conventional passive cooling methods.

Furthermore, the integration of vegetation and water features as part of passive cooling strategies has gained attention. Ojo and Musa (2024) investigated the cooling effects of green roofs and evaporative cooling ponds in institutional buildings in northern Nigeria. Their findings revealed that green roofs could reduce roof surface temperatures by up to 10°C, while evaporative cooling contributed to lowering ambient temperatures around buildings, thereby improving overall thermal comfort.

Climate-responsive design principles remain a foundational principle in passive cooling. According to Nwankwo and Eze (2021), optimizing building orientation to maximize prevailing wind capture and minimize solar exposure is critical in hot and dry climates. Their study in northeastern Nigeria demonstrated that buildings oriented perpendicular to dominant wind directions experienced improved natural ventilation and reduced cooling loads by 28%.

Fenestration design also plays a pivotal role. Ahmed et al. (2022) highlighted the benefits of using high-performance glazing and adjustable shading devices to balance daylighting and solar heat gain. Their research in tropical office buildings found that properly designed windows could reduce cooling energy use by 25% while maintaining adequate natural light.

Challenges and Opportunities in Nigerian passive cooling systems refers. Despite the proven benefits, passive cooling adoption in Nigeria faces challenges such as limited awareness among architects, lack of local building codes enforcing sustainable design, and economic constraints affecting material choices (Abubakar & Suleiman, 2023). However, recent policy initiatives aimed at promoting green building practices provide opportunities for wider implementation (Federal Ministry of Environment, Nigeria, 2024).

Theoretical Model

The theoretical model underpinning the application of passive cooling techniques in the Faculty of Environmental Sciences at Gombe State University is based on climate-responsive architecture and building physics principles, focusing on heat transfer and thermal comfort. The model integrates:

i. **Heat Gain Prevention:** Utilizing shading devices, reflective surfaces, and building orientation to minimize solar radiation and reduce heat ingress.
ii. **Thermal Mass Utilization:** Employing materials with high thermal capacity to absorb heat during the day and release it during cooler periods, thus moderating indoor temperatures.
iii. **Natural Ventilation:** Designing openings and spatial configurations to maximize cross-ventilation, facilitating convective heat removal.
iv. **Building Envelope Optimization:** Enhancing insulation and fenestration design to control heat flow and improve indoor environmental quality.

Methodology

This study adopts a robust mixed-methods case study methodology to comprehensively evaluate the application of passive cooling techniques in the Faculty of Environmental Sciences at Gombe State University (GSU). The research process began with on-site observations and architectural documentation to systematically identify existing passive cooling features, such as building orientation, shading devices, window placement, material selection, and landscape elements. These observations were supplemented by a detailed review of climatic data specific to Gombe's tropical wet-and-dry climate, ensuring that the assessment was contextually grounded.

To deepen the analysis, the study incorporated semi-structured interviews with building users (faculty, staff, and students) to capture subjective experiences of thermal comfort and perceptions of the building's environmental performance. This qualitative data provided insights into the real-world effectiveness and user acceptance of passive cooling strategies.
Quantitative analysis was conducted through dynamic thermal simulations using ECOTECT software. Various passive cooling interventions—such as external shading, increased thermal mass, natural ventilation, roof insulation, and reflective coatings—were modeled to predict their impact on indoor temperature regulation and energy demand. The simulation results were benchmarked against established thermal comfort standards (e.g., ASHRAE 55) and energy consumption metrics.

Triangulation of data from field observations, user feedback, and simulation outputs enabled a holistic evaluation of passive cooling effectiveness. This approach ensured that both the technical performance and occupant satisfaction were considered. The methodology not only identified best practices for passive cooling in educational buildings but also provided evidence-based recommendations tailored to the unique climatic and operational realities of GSU, thereby enhancing the replicability and relevance of the study's findings.

Discussion

Simulation outcomes indicate that the application of passive cooling techniques can reduce the mean indoor temperature by approximately 2°C and decrease cooling load by over 25%. Shading devices and natural ventilation were particularly effective, improving thermal comfort hours and reducing reliance on mechanical cooling. The building's orientation and envelope design were found to be critical factors influencing thermal performance. Reflective roof coatings and increased thermal mass further contributed to lowering heat gain. These findings align with previous studies emphasizing the efficacy of passive cooling in similar climatic contexts (Hu et al., 2023; Akaainjo & Abdullahi, 2018).

Results and Conclusion

The incorporation of passive cooling techniques in the architectural design of the Faculty of Environmental Sciences at Gombe State University reveals a promising approach to improving indoor thermal comfort while simultaneously lowering energy usage. This study highlights the critical importance for architects and urban planners in Nigeria to adopt climate-responsive design strategies, especially when developing institutional facilities. By focusing on the natural environmental conditions, these passive cooling methods can effectively regulate indoor temperatures without relying heavily on mechanical systems, thereby enhancing occupant comfort and reducing operational costs. The findings clearly indicate that passive cooling strategies—such as strategic building orientation, natural ventilation, shading devices, and thermal mass utilization—can significantly mitigate heat gain and improve air circulation within the building. These interventions not only create a more comfortable indoor environment but also contribute to energy efficiency by minimizing the need for air conditioning and artificial cooling systems. This dual benefit aligns with global sustainability goals and addresses local challenges posed by Nigeria's tropical climate. Moreover, this research emphasizes the urgent need for integrating such sustainable design principles into future architectural projects across the region. Institutional buildings, which often have high occupancy rates and extended operational hours, stand to gain substantially from these climate-adaptive solutions. By tailoring passive cooling techniques to the specific climatic context of Gombe State and similar environments, designers can foster healthier, more energy-efficient spaces that support both environmental stewardship and human wellbeing. In conclusion, the study advocates for a paradigm shift in building design practices within Nigeria, encouraging a move away from energy-intensive cooling methods toward more environmentally harmonious approaches. The successful application of passive cooling in the Faculty of Environmental Sciences serves as a valuable model, demonstrating that thoughtful, climate-sensitive architecture can achieve enhanced thermal comfort and sustainability simultaneously. Future architectural endeavors should build on these insights by integrating comprehensive passive cooling strategies that respond directly to local weather patterns and environmental conditions, ultimately promoting sustainable development and improving the quality of life for building occupants.

Recommendations

i. **Integrate Comprehensive Passive Cooling Strategies:** Design buildings with combined shading devices, thermal mass, natural ventilation, and reflective materials tailored to Gombe's hot climate to optimize indoor comfort and reduce energy use.
ii. **Optimize Building Orientation and Layout:** Position buildings and openings to maximize exposure to prevailing winds for natural ventilation and minimize direct solar heat gain.
iii. **Use Locally Available Materials with High Thermal Mass:** Incorporate materials such as stabilized earth blocks or concrete that can absorb and release heat effectively, reducing temperature fluctuations.
iv. **Incorporate Roof and Wall Insulation:** Apply reflective coatings and insulation to roofs and walls to reduce heat penetration, especially during peak daytime temperatures.
v. **Promote Awareness and Capacity Building:** Educate architects, planners, and stakeholders on the benefits and implementation of passive cooling to encourage widespread adoption in institutional buildings.

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