



## Climate-Responsive Architecture: Optimizing Passive Cooling Strategies for Enhanced Thermal Comfort in the Design of University Senate Buildings

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### Abstract

The rising demand for energy-efficient and thermally comfortable buildings in hot-dry regions underscores the need for climate-responsive architecture in Nigeria's institutional infrastructure. Despite global advances in passive design, many university senate buildings in northern Nigeria remain poorly optimised, resulting in excessive heat gain and high cooling energy demand. This study investigates the passive cooling performance of selected senate buildings to enhance thermal efficiency and environmental sustainability. Using building simulation software, wall, roof, and glazing configurations were analysed for thermal transmittance (U-values) and energy performance. The results revealed that incorporating polystyrene insulation, double glazing, and green roofing systems significantly reduced U-values and improved indoor thermal comfort compared to conventional designs. Findings affirm that design parameters such as material composition and envelope detailing directly influence building energy performance. The study emphasises the importance of integrating passive cooling strategies in institutional design to align with national and international energy efficiency standards. It concludes by recommending the adoption of simulation tools in design practice, capacity-building for designers, and policy reforms promoting low-carbon building envelopes. Future research should extend simulations to life-cycle analysis and real-time monitoring for broader regional applicability.

**Keywords:** Passive Cooling, Thermal Efficiency, Energy Performance, Building Envelope, Sustainable Architecture

### Introduction

The growing demand for sustainable, energy-efficient buildings in the face of climate change has intensified global attention on passive cooling design strategies, especially in hot, dry regions such as northern Nigeria. Buildings in this climatic zone are highly vulnerable to overheating, leading to excessive mechanical cooling energy consumption and thermal discomfort for occupants (Obamoh et al., 2025; Khechiba et al., 2023). In developing nations, where over 60% of the built environment is naturally ventilated, reliance on air-conditioning is both economically and environmentally unsustainable (Verma & Rakshit, 2022). Consequently, the integration of passive cooling principles, through building form, orientation, materials, shading, and ventilation—has become a viable pathway toward achieving energy efficiency and thermal comfort (Aule, 2023; Fagam et al., 2025; Okiye et al., 2023). Despite global progress, Nigeria's public institutional buildings—particularly university senate buildings, remain poorly optimised for passive cooling, resulting in high internal temperatures and increased energy demand (Elenga et al., 2025). The problem is compounded by poor material selection, inadequate shading, and limited landscape integration. The absence of climate-responsive design frameworks undermines user comfort and operational efficiency, contrary to the National Building Energy Efficiency Code (BEEC) and international sustainability standards such as those of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the United Nations Environment Programme (UNEP) (Geissler et al., 2018).

This study aims to evaluate and simulate the passive cooling performance of selected university senate buildings in northern Nigeria to enhance their thermal efficiency. The specific objectives are: (i) to assess the adoption of passive cooling elements in existing senate buildings; (ii) to analyse their thermal performance through material and envelope simulation; and (iii) to propose optimised design strategies that align with ASHRAE indoor comfort

standards. The research is relevant in modern times as the building sector accounts for nearly 37% of global energy-related CO<sub>2</sub> emissions, according to the World Green Building Council (WGBC) (Adams et al., 2019). For architects, planners, and policymakers, understanding passive cooling performance is crucial to achieving Nigeria's Sustainable Development Goals (SDGs 7, 11, and 13) and to reducing the ecological footprint of institutional infrastructure. By demonstrating how design decisions influence indoor comfort and energy use, this study provides a scientific basis for climate-responsive architecture in tropical universities.

### Methods and Materials

This study adopted a mixed-method research design combining descriptive and experimental strategies to evaluate how passive cooling techniques can enhance indoor thermal conditions in the proposed Senate Building design for Kano State's hot-dry climate. The mixed-method approach, integrating qualitative case studies and quantitative computer simulations, was selected for its robustness in architectural performance analysis, as it allows triangulation between empirical field data and predictive modelling outcomes (Creswell & Creswell, 2017; Akotia et al., 2024; Weyant, 2022). The descriptive aspect employed case studies of senate buildings within the hot-dry climatic zone of Nigeria, specifically at Ahmadu Bello University (Zaria), Bayero University (Kano), and Umaru Musa Yar'adua University (Katsina). Case study methodology supports in-depth contextual understanding of environmental design performance using multiple data sources (Yin, 2018). Data collection tools included checklists, photographs, sketches, and visual surveys to document passive cooling elements, including orientation, shading, vegetation, and ventilation strategies. These qualitative tools ensured comprehensive environmental documentation and enhanced methodological rigour (Groat & Wang, 2013). The experimental component utilised building performance simulation through Design Builder software, an advanced platform that integrates energy, daylighting, and thermal comfort modelling within a BIM environment (Aule, 2023; Ayoosu et al., 2020; Özer, 2025). The proposed building model, created in Autodesk Revit 2023, was exported to DesignBuilder as a gbXML file for detailed thermal analysis. Local meteorological data for Wudil were incorporated to simulate realistic climate conditions. This approach aligns with contemporary best practices in sustainable design research, where simulation tools provide replicable and measurable performance insights (Hassanzadeh et al., 2024). A purposive sampling technique was used to select representative senate buildings with similar typology and climatic conditions, consistent with qualitative sampling logic for architectural inquiry (Palinkas et al., 2015). Research variables—building form and orientation, envelope, vegetation, ventilation, shading devices, water features, and green roofs/walls—were derived from literature and treated as independent parameters influencing indoor thermal comfort. Quantitative results were statistically presented using tables and graphs, while qualitative interpretations were discussed descriptively, ensuring methodological triangulation and validity. The integration of case-based observation and computer simulation enabled a comprehensive evaluation of passive cooling strategies for sustainable institutional building design in hot-dry climates.

### Results

#### Case Study One: Senate Building of Bayero University, Kano

The analysis of Table 1, in the context of the Bayero University Kano Senate Building, reveals a moderately practical application of passive cooling strategies, resulting in an overall average appraisal of "Good" (mean score  $\approx$  2.9). The building's orientation and form, rated 4, demonstrate commendable climatic responsiveness. Its northeast–southwest alignment minimises solar heat gain on longer façades while allowing controlled daylight penetration, consistent with passive design principles for tropical climates (Ayoosu et al., 2020; Justice et al., 2024). The integration of courtyards at both ends further enhances natural ventilation and daylight access, promoting thermal comfort and energy efficiency (Aule et al., 2023; Ayoosu et al., 2020; Kolani et al., 2023).

The building envelope, with aluminium cladding and extensive glazing, scored 3, indicating moderate performance. While aluminium and glass contribute to aesthetics and durability, their high thermal conductivity can increase internal heat load if not adequately insulated. This limits thermal efficiency compared to more sustainable façade systems such as double-skin façades or ventilated envelopes (Aule et al., 2024; Ruiz-Valero et al., 2021). The absence of low-emissivity glass or shading-integrated glazing reduces the envelope's potential to regulate indoor temperature effectively.

The landscape and vegetation, rated 4, play a vital role in modifying the site microclimate. Vegetative buffers of trees and shrubs reduce ground temperature and filter solar radiation, aligning with sustainable campus design practices that enhance outdoor comfort and reduce cooling demands (Alabi et al., 2025). Similarly, natural ventilation, also rated 4, benefits from the courtyard strategy, operable window systems, and well-placed openings that facilitate cross-airflow. This approach effectively complements the building's vertical circulation systems and reduces reliance on mechanical cooling (Anselm & Ikejiofor, 2023).

However, the lack of water features and green roofs/walls (rated 1 each) marks a significant limitation in the building's passive cooling strategy. These features could have enhanced evaporative cooling and reduced surface

temperature. Their absence reflects a missed opportunity to improve environmental performance and visual relief in the arid Kano context (Bello et al., 2025). In brief, although the Senate Building demonstrates an understanding of passive cooling strategies through its orientation, ventilation, and landscape design, its envelope and lack of advanced green technologies limit its overall sustainability performance.

**Table 1: Passive cooling appraisal for BUK Senate building.**

Appraisal Key: 5 = Excellent; 4 = Very good; 3 = Good; 4 = Fair; 1=Poor

S/N	Variable	Feature	Adoption	Appraisal
1	Building form and orientation	Shape of the building and the solar orientation.	The form is oriented NE-SW.	4
2	Building envelope	Cladding, double skin, etc	Aluminium cladding is adopted throughout the façade.	3
3	Landscape and vegetation	Soft and hard landscape elements.	Trees, shrubs, and hedges are planted throughout the site.	4
4	Natural ventilation	Windows, vents, openings, courtyards, etc	Curtain walls were used on most of the building with fixed and operable spaces. The courtyard improves cross-ventilation in offices.	4
5	Shading	Shading devices, overhangs, screen walls, etc	Overhangs were adopted at each floor level, and recesses were provided at some locations, such as the entrance.	3
6	Use of water features	Fountains, ponds and pools.	No form of water feature was adopted.	1
7	Green Roof/Walls	Intensive/extensive green roof, trellis with climbers, etc	No form of green roof/wall was adopted.	1

### Case Study Two: Senate Building of Ahmadu Bello University, Zaria

The analysis of Table 2, within the context of the Ahmadu Bello University (ABU) Senate Building, demonstrates a thoughtful integration of several passive cooling techniques suited to its hot-dry climatic conditions. With an overall mean appraisal of approximately 2.9, the building exhibits moderate thermal performance, balancing architectural grandeur with climatic functionality. The building form and orientation, rated 4, reflects a strong design approach. Its square configuration with a central tower minimises solar exposure across façades, while balanced orientation allows adequate cross-ventilation in all directions. This geometry aligns with findings by Kolani et al. (2023), who emphasise that compact forms reduce heat gain and promote stable internal temperatures in tropical buildings.

**Table 2: Thoughtful integration of several passive cooling techniques at Ahmadu Bello University (ABU) Senate Building.**

Appraisal Key: 5 = Excellent; 4 = Very good; 3 = Good; 4 = Fair; 1=Poor

S/N	Variable	Feature	Adoption	Appraisal
1	Building form and orientation	Shape of the building and the solar orientation.	The building form is square with a central tower. Any of the axes is appropriate.	4
2	Building envelope	Cladding, double skin, etc	Concrete structural elements constitute the envelope.	3
3	Landscape and vegetation	Soft and hard landscape elements.	Trees, shrubs, and hedges are planted throughout the site.	4
4	Natural ventilation	Windows, vents, openings, courtyards, etc	The courtyard improves cross-ventilation in offices.	4
5	Shading	Shading devices, overhangs, screen walls, etc	Recesses, overhangs, vertical and horizontal devices were adopted.	3
6	Use of water features	Fountains, ponds and pools.	No form of water feature was adopted.	1

7	Green Roof/Walls	Intensive/extensive green roof, trellis with climbers, etc	No form of green roof/wall was adopted.	1
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The building envelope, rated 3, consists mainly of reinforced concrete and glass, providing thermal mass that moderates diurnal temperature variations. However, the absence of advanced insulation or reflective cladding systems limits its overall thermal efficiency. As Aule et al. (2024) and Ruiz-Valero et al. (2021) note, concrete-heavy façades without insulation can retain heat, thus increasing cooling loads. The integration of curtain wall systems in the podium section improves daylight access but requires efficient shading to mitigate glare and heat ingress.

The landscape and vegetation, rated 4, demonstrates effective use of trees and shrubs to create a microclimate buffer around the building. Vegetation shields lower floors from direct wind and solar radiation, consistent with Alabi et al. (2025), who highlight landscape design as an integral element of passive environmental control in institutional architecture. Similarly, natural ventilation (rated 4) benefits from courtyards and single-banked corridors, ensuring consistent airflow.

Shading devices, rated 3, including recesses, verandas, and vertical fins, provide substantial solar protection but could be enhanced with adjustable louvres or light shelves for adaptive shading. However, the absence of water features and green roofs/walls (rated 1 each) indicates underutilisation of evaporative cooling and vegetative insulation opportunities (Bello et al., 2025). Overall, ABU's Senate Building successfully integrates form, orientation, and landscape to enhance climatic responsiveness, but lacks advanced passive and bioclimatic innovations to achieve optimal thermal efficiency.

### Case Study Three: Senate Building of Umaru Musa Yar'adua University, Katsina

The analysis of Table 3 for the Umaru Musa Yar'adua University (UMYU) Senate Building demonstrates an appreciable application of passive cooling strategies, achieving an average performance rating of "Good" (mean score  $\approx 2.9$ ). The building form and orientation, rated 4, are key contributors to its environmental responsiveness. The rectangular shape, with the more extended façade oriented north–south, effectively reduces solar heat gain on the more exposed sides while enhancing daylighting and cross ventilation (Justice et al., 2024). This configuration aligns with best practices in passive cooling design for hot-dry climates, where minimising solar exposure on east-west façades is essential to thermal comfort (Aule, 2023; Ayoosu et al., 2020; Kolani et al., 2023).

The building envelope, rated 3, exhibits moderate thermal efficiency. The use of reinforced concrete provides thermal mass that delays heat transfer, while smaller window openings help reduce solar radiation infiltration—an appropriate choice for the hot-dry region of Katsina. However, the absence of advanced insulation or double-glazing limits its potential for improved energy performance (Ruiz-Valero et al., 2021). Reinforced concrete gutters enhance roof durability and water management, aligning with sustainable construction practices in arid environments.

Landscape and vegetation (rated 4) significantly contribute to the building's passive cooling performance. The use of trees and shrubs within the courtyard and around the structure helps absorb solar radiation, cool the air through evapotranspiration, and improve the microclimate (Alabi et al., 2025). Similarly, natural ventilation, also rated 4, is enhanced by the courtyard system and single-banked corridors that support cross-airflow and the stack effect, reducing reliance on mechanical ventilation systems (Anselm & Ikejiofor, 2023).

Shading devices, rated 3, include deep verandas that reduce solar penetration while improving indoor comfort. Nonetheless, the absence of green roofs or walls (rated 1) and water features reduces opportunities for additional cooling and biodiversity enhancement. Incorporating these features could have strengthened the building's sustainability profile (Bello et al., 2025). Overall, the UMYU Senate Building effectively demonstrates climatic responsiveness through its orientation, landscape integration, and natural ventilation, though future retrofits could enhance its envelope insulation and adopt living roofs for improved passive cooling performance.

**Table 3: Appreciable application of passive cooling strategies at Umaru Musa Yar'adua University (UMYU) Senate Building.**

Appraisal Key: 5 = Excellent; 4 = Very good; 3 = Good; 2 = Fair; 1=Poor

S/N	Variable	Feature	Adoption	Appraisal
1	Building form and orientation	Shape of the building and the solar orientation.	The building is a combination of two half-octagonal wings. The longer sides are oriented North to South.	5
2	Building envelope	Cladding, double skin, etc	The building is constructed with hollow blocks and concrete structural elements.	3
3	Landscape and vegetation	Soft and hard landscape elements.	Trees, shrubs, and hedges are planted throughout the site.	4
4	Natural ventilation	Windows, vents, openings, courtyards, etc	Curtain walls were used on most buildings, with both fixed and operable spaces. The courtyard improves cross-ventilation for the central offices.	4
5	Shading	Shading devices, overhangs, screen walls, etc	Recesses were provided in some parts of the building.	3
6	Use of water features	Fountains, ponds and pools.	A fountain is installed in the central courtyard.	4
7	Green Roof/Walls	Intensive/extensive green roof, trellis with climbers, etc	No form of green roof/wall was adopted.	1

### Comparison of Case Study Findings

The comparative appraisal in Table 4 shows consistent strengths across the three senate buildings in orientation, courtyard-driven ventilation, and perimeter vegetation, with the main weaknesses concentrated on façades and the near-universal absence of green roofs and water features. Courtyards and properly oriented long façades (as in BUK's NE-SW plan and UMYU's north-south longer sides) are well-documented to organise airflow, provide thermal buffering, and reduce peak indoor temperatures in hot-dry climates; courtyard geometries in recent CFD and empirical studies have been shown to improve night-time flushing and daytime shading when adequately sized and connected to internal zones (Khan et al., 2023; Zhou et al., 2025). Vegetation around all three buildings amplifies these benefits by lowering local air temperatures through shading and evapotranspiration, mechanisms that consistently reduce near-surface temperatures and improve thermal comfort in campus settings (Al-Hajri et al., 2025; Aule, 2023; Soltanifard, 2025).

However, the repeated use of aluminium cladding and extensive glazing at BUK and ABU highlights a vulnerability: lightweight reflective claddings and large glazed areas can raise façade surface temperatures and internal heat gains unless combined with ventilated cavity details, external insulation, or high-performance glazing and shading systems. Recent façade-performance analyses and renovation studies emphasise that material choice and façade details materially affect cooling loads and life-cycle environmental impacts, recommending ventilated façades, insulation upgrades, or adaptive shading to mitigate overheating (Tabatabaei & Fayaz, 2023; Štompf et al., 2025). The complete lack of green roofs and limited use of water features—except UMYU's central fountain—represents missed opportunities for roof-level thermal buffering and evaporative cooling; systematic reviews show green roofs can reduce peak surface temperatures and modestly lower building cooling demand, particularly in dry climates where properly designed systems can deliver measurable microclimate benefits (De-Cristo et al., 2025; Perivoliotis et al., 2023; Tseng et al., 2022).

In brief, the three cases demonstrate sound passive planning (orientation, courtyards, vegetation) appropriate for Kano's hot-dry context, but their sustainability performance would be strengthened by retrofit or design interventions focused on façade improvement, optimised shading (parametric/design-for-performance), and the selective introduction of green roofs or evaporative elements to close remaining thermal-comfort gaps (Khan et al., 2023; Tabatabaei & Fayaz, 2023; De-Cristo et al., 2025).

**Table 4: Comparative strengths and weaknesses across the three senate buildings.**

S/N	Variable	BUK Senate Building	ABU Senate Building	UMYU Senate Building
1	Building form and orientation	The form is oriented NE-SW.	The building form is square with a central tower. Any of the axes is appropriate.	The building is a combination of two half-octagonal wings. The longer sides are oriented North to South.
2	Building envelope	Aluminium cladding is adopted throughout the façade.	Concrete structural elements constitute the envelope.	The building is constructed with hollow blocks and concrete structural elements.
3	Landscape and vegetation	Trees, shrubs, and hedges are planted throughout the site.	Trees, shrubs, and hedges are planted throughout the site.	Trees, shrubs, and hedges are planted throughout the site.
4	Natural ventilation	Curtain walls were used on most of the building with fixed and operable spaces. The courtyard improves cross-ventilation in offices.	The courtyard improves cross-ventilation in offices.	Curtain walls were used on most of the buildings, with both fixed and operable spaces. The courtyard improves cross-ventilation for the central offices.
5	Shading	Overhangs were adopted at each floor level, and recesses were provided at some locations, such as the entrance.	Recesses, overhangs, vertical and horizontal devices were adopted.	Recesses were provided in some parts of the building.
6	Use of water features	No form of water feature was adopted.	No form of water feature was adopted.	A fountain is installed in the central courtyard.
7	Green Roof/Walls	No form of green roof/wall was adopted.	No form of green roof/wall was adopted.	No form of green roof/wall was adopted.

### Simulation Results of Proposed Senate Building

Table 5 presents the simulation results for three critical building envelope elements—walls, roofs, and glazing—each evaluated for their influence on indoor thermal performance and compliance with ASHRAE comfort standards under Wudil climatic conditions. The wall simulations reveal that incorporating insulation has a marked impact on thermal comfort: W2, which integrates a 50 mm polystyrene layer, achieves a U-value of 0.32 W/m<sup>2</sup>K, significantly lower than W1's 3.11 W/m<sup>2</sup>K without insulation. This difference corresponds to a 4°C reduction in indoor temperature, confirming findings from recent studies that highlight insulation as an effective passive cooling measure in hot-dry climates (Bentoumi et al., 2024; Ham et al., 2024). By minimising conductive heat gain and stabilising diurnal temperature fluctuations, W2 aligns with best-practice recommendations for thermally efficient façades in regions where mean monthly temperature variations exceed 10°C (Abdalla et al., 2025).

**Table 5: Simulation results for influence on indoor thermal performance.**

Building Element	Code	Description	Thickness(mm)	U-Value(W/m <sup>2</sup> )
Wall	W1	Outside: external rendering	12.5	3.11
		Hollow concrete block	225	
	W2	Internal mortar plaster	12.5	0.32
		Inside: internal paint	0.1 (Negligible)	
Roof	R1	Outside: cement rendering	12.5	0.55
	R2	Polystyrene	50	
		Hollow concrete block	225	
Glazing	G1	Internal mortar plaster	12.5	0.38
		Inside: internal paint	0.1 (Negligible)	
Roof	R1	Corrugated roofing sheet	50	0.38
	R2	Extensive green roof	150	
Glazing	G2	Soil layer		5.32
		Drainage layer		
Glazing	G1	Roof membrane		1.60
		Single glazing with a blind	8	
Glazing	G2	Double glazing with a blind	20	1.60

Similarly, the roof simulations emphasise the substantial role of upper-envelope design in reducing indoor heat accumulation. The insulated corrugated roof (R1) and extensive green roof (R2) both outperform the baseline configuration, with R2's U-value of 0.38 demonstrating superior insulation and heat buffering. Green roofs have been consistently shown to reduce indoor peak temperatures and cooling demand by several degrees through evapotranspiration and enhanced thermal mass (De-Cristo et al., 2025; Seo et al., 2023). For buildings in hot-dry regions like Kano, such systems offer both environmental and operational advantages, moderating interior temperatures and mitigating rooftop heat islands. Finally, glazing simulations reveal that upgrading from single glazing (G1) to double glazing with blinds (G2) substantially improves indoor conditions, reducing U-value from 5.32 to 1.60 W/m<sup>2</sup>K and indoor temperature by about 4°C. This result echoes findings that improved glazing systems can cut solar heat gain by 40–60% and keep operative temperatures within the ASHRAE comfort range (Chen et al., 2025; Chen et al., 2023). Overall, combining W2, R2, and G2 (Scenario B) maintains indoor temperatures within 23–28°C, confirming that integrated passive strategies are the most effective and sustainable approach to achieving thermal comfort in institutional buildings in northern Nigeria's hot-dry climate (Bienvenido-Huertas et al., 2024; Sani et al., 2025).

## Discussion

The findings of this study reveal that integrating passive cooling design strategies, material optimisation, and building envelope enhancements significantly improve thermal comfort and energy efficiency in institutional buildings in hot-dry regions such as Kano, Nigeria. The comparative simulations conducted on the proposed Senate building demonstrate that the use of improved materials—specifically insulated walls (W2), extensive green roofs (R2), and double glazing (G2)—substantially reduces indoor operative temperatures to within the comfort range of 18–28 °C reported by Bienvenido-Huertas et al. (2024). These results affirm that building envelopes have the most significant influence on thermal regulation and underscore the critical importance of proper material selection and passive design adaptations to mitigate indoor heat gain. Similar findings have been reported by Ham et al. (2024) and De-Cristo et al. (2025), who concluded that improved insulation and vegetative

roof systems effectively enhance indoor comfort while reducing energy demand. The study thus provides empirical evidence supporting a shift away from reliance on active cooling toward more sustainable, climate-responsive architectural solutions suitable for sub-Saharan contexts.

For government and regulatory authorities, these results underscore the urgent need to update and enforce local building codes to reflect energy-efficient design standards suitable for hot, dry climates. Policymakers can adopt insights from this study to integrate thermal performance benchmarks into public building procurement and approval frameworks. Doing so would align with Nigeria's commitments under the National Energy Efficiency Action Plan and the Paris Climate Agreement. Urban planners and designers also stand to benefit from the findings by rethinking master plans and architectural layouts that prioritise orientation, courtyard systems, and shading. By incorporating natural ventilation, vegetation, and material innovation into design practice, planners can reduce heat stress, improve occupant comfort, and extend building lifespans. These findings are consistent with Abdalla et al. (2025) and Chen et al. (2023), who emphasise that orientation, envelope design, and shading can cut cooling loads by up to 40% in tropical climates when applied holistically.

For environmentalists and sustainability advocates, the findings reinforce the environmental benefits of integrating green roofs and low-emissivity glazing into institutional design, as these reduce heat island effects and greenhouse gas emissions. Researchers and academic institutions can also use the study as a foundation for further quantitative assessments of material combinations and their energy performance across different climatic zones in Nigeria. Stakeholders, including university management and construction firms, can apply these results to reduce operational costs associated with air conditioning while creating healthier, more conducive learning and working environments. The 4°C reduction in indoor temperature observed in the improved scenario demonstrates the tangible benefits of adopting low-cost, locally adaptable technologies.

In brief, this study provides a practical, evidence-based framework for enhancing thermal comfort in institutional buildings in Nigeria's hot-dry regions. It bridges the gap between sustainable design theory and context-specific implementation, offering insights that are not only academically valuable but also relevant to policymakers, architects, planners, and environmental advocates striving for a more energy-efficient built environment. By advancing passive cooling research in Africa's arid zones, this work sets the stage for broader interdisciplinary collaborations to achieve thermally resilient, sustainable architecture across the continent.

## Conclusion

The study evaluated passive cooling performance in selected university senate buildings and through simulation of proposed design elements. Findings reveal that optimising the building envelope using insulated walls (W2), extensive green roofs (R2), and double glazing (G2) significantly reduced indoor operative temperatures, maintaining thermal comfort within the Bienvenido-Huertas et al. (2024) standard range of 18–28°C. Courtyards, vegetation, and appropriate building orientation also contributed to improved airflow and reduced heat gain. Compared with buildings that lacked adequate shading or insulation, those that did showed higher indoor temperatures and reduced comfort. The study thus demonstrates that the strategic application of passive design principles can effectively enhance building performance and occupant comfort in hot-dry climates. In conclusion, the research confirms that energy-efficient materials and design interventions—such as thermal insulation, vegetated surfaces, and optimised glazing—offer viable solutions to overheating challenges in institutional buildings. Integrating these measures not only improves thermal comfort but also reduces dependency on mechanical cooling systems, thereby cutting operational energy costs and supporting environmental sustainability.

## Recommendations

1. The study recommends that government agencies and educational authorities adopt passive design principles as mandatory criteria in building codes and university project approvals.
2. Architects and planners should prioritise orientation, natural ventilation, and insulation during design development, while policymakers should promote incentives for the use of sustainable materials.
3. Further research should include field validation of simulation results, cost-benefit analysis of passive systems, and exploration of renewable energy integration to complement passive cooling strategies in institutional and public buildings across different climatic zones in Nigeria.

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