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Building Design Impacts and Climate Resilience in Katsina State: A Systematic Review of Sustainable Architectural Practices in Hot-Dry Climates

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ABSTRACT
Katsina State in northern Nigeria faces significant challenges from its hot-dry Sahelian climate, intensified by climate change. This systematic review synthesizes literature on how building design choices influence environmental, social, economic, and resilience outcomes. Traditional Hausa architecture, with features like thick mud walls and courtyards, provides effective passive cooling, while modern concrete designs often exacerbate overheating and energy demands. Barriers to sustainable practices include limited awareness and weak policy enforcement. Flood vulnerability further compounds risk in many areas. The review highlights research gaps in localized empirical studies and recommends hybrid vernacular-modern approaches, updated building codes, and capacity building to enhance climate resilience.

INTRODUCTION

Katsina State, located in Nigeria's northwest, experiences a hot-dry climate characterized by high daytime temperatures (often exceeding 35–40°C), intense solar radiation, low humidity, and variable rainfall that increases risks of both drought and flooding (Alegbe et al., 2025). Buildings in this region significantly influence energy consumption, thermal comfort, and vulnerability to climate extremes. Globally, the building sector contributes substantially to carbon emissions; in hot-dry zones like Katsina, poorly designed structures amplify indoor heat stress and operational energy needs (Alegbe et al., 2025).

Traditional Hausa architecture has long demonstrated climate-responsive design through thick earthen walls (tubali) for thermal mass, central courtyards for natural ventilation, and strategic orientation to minimize solar gain (Abubakar, 2014; Keeping Cool Under the Hot Arewa Sun, 2022). However, rapid urbanization, university expansions (such as at Federal University Dutsin-Ma), and preference for modern sandcrete and concrete constructions have shifted away from these practices, leading to higher energy demands and reduced resilience (Agboola et al., 2023; Hassan et al., 2023).

This systematic review examines the nature of building design impacts in Katsina State and pathways toward sustainable, climate-resilient practices. The central research question is: How do contemporary and traditional building designs affect climate resilience and sustainability in Katsina's hot-dry climate, and what strategies can integrate indigenous knowledge with modern requirements?

MATERIALS AND METHODS

This review adopted a PRISMA-inspired systematic approach. Searches were performed in Google Scholar, ResearchGate, FUDMA Journal of Sciences, and other repositories using keywords such as "building design Katsina," "Hausa architecture passive cooling," "green building barriers Nigeria," "flood impacts Dutsin-Ma," and "climate resilience buildings northern Nigeria." Inclusion criteria covered peer-reviewed articles, theses, reports, and empirical studies from 2010–2025 focused on Nigeria's northern or hot-dry contexts. Approximately 70 sources were screened, with over 40 synthesized thematically into impacts, traditional vs. modern comparisons, barriers, and recommendations. Limitations include the scarcity of long-term field monitoring data specific to Katsina and reliance on modelling or single-case studies.

RESULTS AND DISCUSSION

Climate Context of Katsina State

Katsina State lies in the Sahel-Sudan savanna transition zone with mean annual temperatures of 25–30°C and peaks above 40°C during the dry season (March–May). Rainfall is concentrated in a short-wet season (June–September), often leading to intense storms and flooding (Hassan et al., 2023). Climate projections under various scenarios (e.g., RCP 4.5 and 8.5) indicate temperature increases of approximately 4–5 °C by 2100 in Cluster 2 regions that include Katsina, heightening overheating risks and energy demands for cooling (Alegbe et al., 2025). Climate projections indicate notable warming trends that will exacerbate building performance challenges.

As summarized in Table 1, temperature increases are projected under various Representative Concentration Pathway (RCP) scenarios, with significant implications for thermal comfort, cooling demand, and flood resilience.

Table 1: Projected Temperature and Precipitation Changes for Katsina State/Northern Nigeria under RCP Scenarios (Relative to Historical Baseline)

Rank	Barrier	RII	Implications for Hot-Dry Climates in Katsina State
1	Lack of understanding of green building technologies	0.79	Limits adoption of passive cooling and vernacular-hybrid designs
2	Absence of institutions/policies/guidelines	0.77	Weak enforcement of climate-responsive building codes
3	Scarcity/unclear sustainable materials & equipment	0.76	Difficulty sourcing stabilized earth blocks or shading systems
4	Poor stakeholder collaboration & communication	0.76	Hinders integration of architects, clients, and local masons
5	Preference for conventional practices & long approval processes	0.75–0.76	Perpetuates high-energy concrete designs despite flood/heat risks

Sources: Alegbe et al. (2025); World Bank Climate Knowledge Portal (2021).

These conditions directly challenge building performance. High solar gain on east-west facades, dust-laden harmattan winds, and limited nighttime cooling reduce passive potential unless designs intervene effectively. Urban sprawl and concrete development intensify urban heat island effects in Katsina metropolis and Dutsin-Ma (Hassan et al., 2023). These projections underscore the urgency for climate-resilient building practices in Katsina State.

Impacts of Building Design in Katsina State

Environmental Impacts

Modern concrete-dominated buildings increase both embodied carbon (from cement production) and operational emissions due to high cooling loads. In hot-dry climates, inadequate orientation and low thermal mass cause indoor temperatures to rise 5–10°C above outdoor levels, driving reliance on mechanical systems where electricity is available (Abubakar, 2014; Alegbe et al., 2025). Construction activities contribute to habitat loss, dust pollution, and waste generation. The spatial distribution of rainfall for example is shown in Figure 1.

Urban expansion in Dutsin-Ma has increased built-up areas, reducing permeable surfaces and worsening runoff (Hassan et al., 2023). Traditional designs, by contrast, use low-embodied-energy local materials and support biodiversity through integrated landscaping.

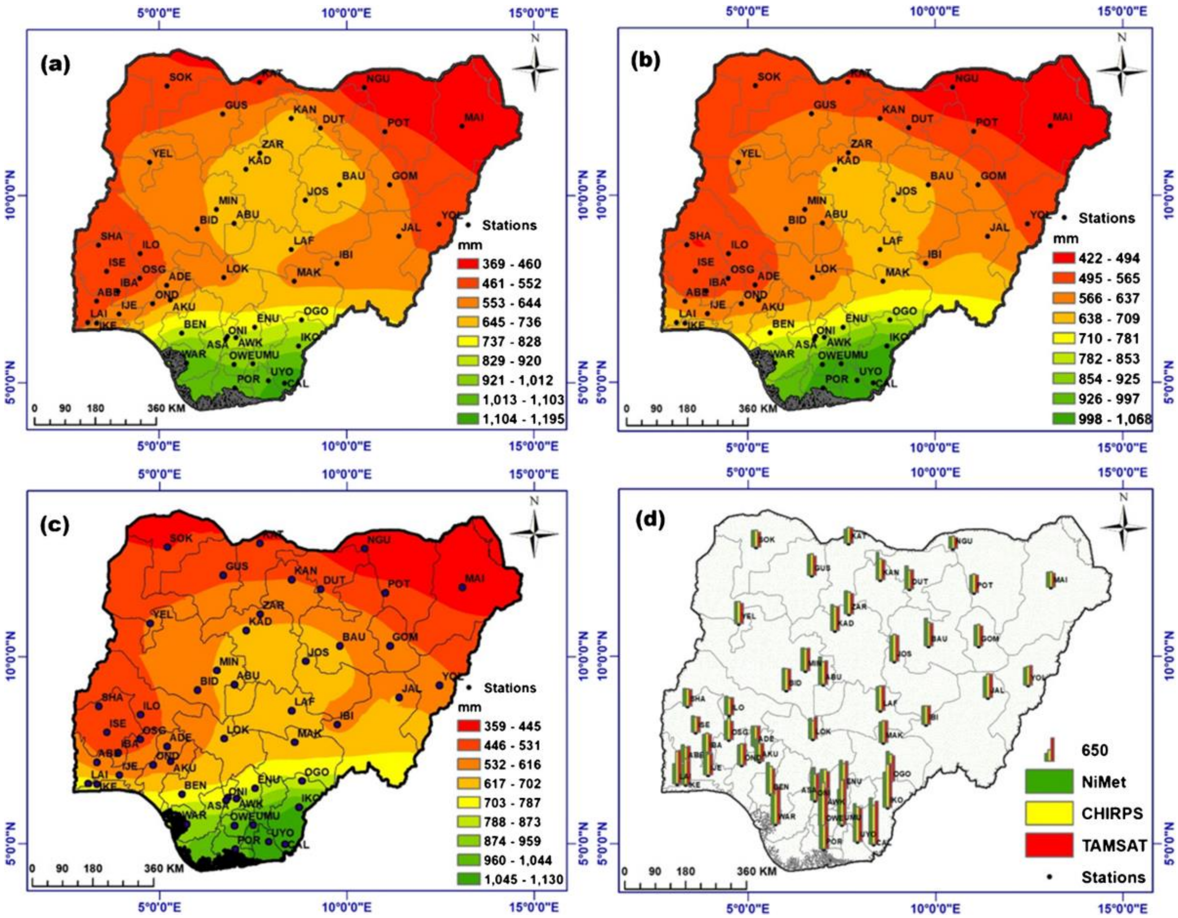

Figure 1: Spatial Distribution of Rainfall Across Nigeria (Including Northern States like Katsina)

Thermal Comfort and Energy Performance

Simulation and case studies show that conventional buildings in northern Nigeria suffer from overheating, lowering occupant productivity and increasing heat-related health risks. The proposed FUDMA Senate Building thesis demonstrated that passive techniques such as courtyards for stack ventilation, north-south orientation, high thermal-mass walls, and shaded spaces could reduce cooling energy demand by up to 30% and improve indoor comfort significantly (Abubakar, 2014). Table 2 presents a comparative overview of thermal performance between traditional Hausa and modern buildings.

Table 2: Thermal Performance Comparison of Traditional Hausa and Modern Buildings in Northern Nigeria Hot-Dry Climates

Building Type	Mean Indoor Temperature Reduction (vs. Outdoor)	Cooling Energy Demand Reduction (%)	Key Contributing Features
Traditional Hausa (Courtyard + Thick Walls)	4–6°C	20–40% (passive only)	Thermal mass, stack ventilation, shading
Modern Conventional (Sandcrete/Concrete)	Minimal or +2–5°C above comfort	Baseline (high reliance on AC)	Limited passive elements
Hybrid/Passive-Enhanced (e.g., FUDMA Senate Proposal)	3–5°C	Up to 30%	Optimized orientation + thermal mass

Sources: Abubakar (2014); Keeping Cool Under the Hot Arewa Sun (2022); Noma (2022).

Traditional Hausa features, including thick mud walls and vaulted interiors, achieve natural temperature reductions of 4–6°C compared to ambient conditions through thermal lag and buoyancy-driven airflow (Keeping Cool Under the Hot Arewa Sun, 2022; Noma, 2022). Bioclimatic strategies remain underutilized in most contemporary residential and institutional buildings in Katsina.

Flood and Extreme Event Resilience

Flooding poses a major threat in low-lying areas of Dutsin-Ma, with studies reporting that up to 50% of affected buildings experience collapse, wall soaking, or material loss due to poor siting, inadequate foundations, and lack of integrated drainage (Hassan et al., 2023). Table 3 quantifies the reported impacts and links them to design deficiencies. Climate change is projected to increase the frequency and intensity of such events in parts of Katsina (Alegbe et al., 2025). Resilient design elements such as elevated structures, flood-resistant materials, and permeable surfaces are rarely incorporated.

Table 3: Reported Impacts of Flooding on Buildings and Communities in Dutsin-Ma Local Government Area

Impact Category	Description/Details	Approximate Extent/Percentage	Linked Design Deficiencies	Recommended Mitigations
Structural Damage/Collapse	Building collapse or severe caving	Up to 50% of affected buildings	Poor foundations, non-elevated structures	Elevated foundations; flood-resistant materials
Wall Soaking & Material Loss	Walls soaked; loss of building materials	21% material loss	Impermeable surfaces; poor drainage integration	Integrated drainage; permeable paving
Other Damage	Road blockage siltation, displacement	Widespread in high-risk wards	Lack of zoning & resilient siting	Better urban planning & zoning

Sources: Hassan et al. (2023).

Socio-Economic and Cultural Impacts

High energy costs strain households and institutions amid unreliable power supply. Culturally, the shift from Hausa vernacular erodes traditional skills, privacy-oriented compound layouts, and aesthetic motifs that reinforce community identity (Noma, 2022). Sustainable designs, however, could generate local employment in earthen construction and lower long-term maintenance expenses.

Traditional Hausa Architecture as a Foundation for Sustainability

Hausa traditional building practices exemplify climate-responsive design developed over centuries. Key elements include rammed earth or sun-dried mud bricks with excellent thermal properties, central courtyards that promote cross-ventilation and shading, small high-level openings to control dust and glare, and reflective surfaces (Abubakar, 2014; Keeping Cool Under the Hot Arewa Sun, 2022). These features provide passive cooling without mechanical systems, support privacy and communal living, and utilize biodegradable, locally sourced materials with low embodied energy. The schematic layout of a traditional compound is shown in Figure 2.

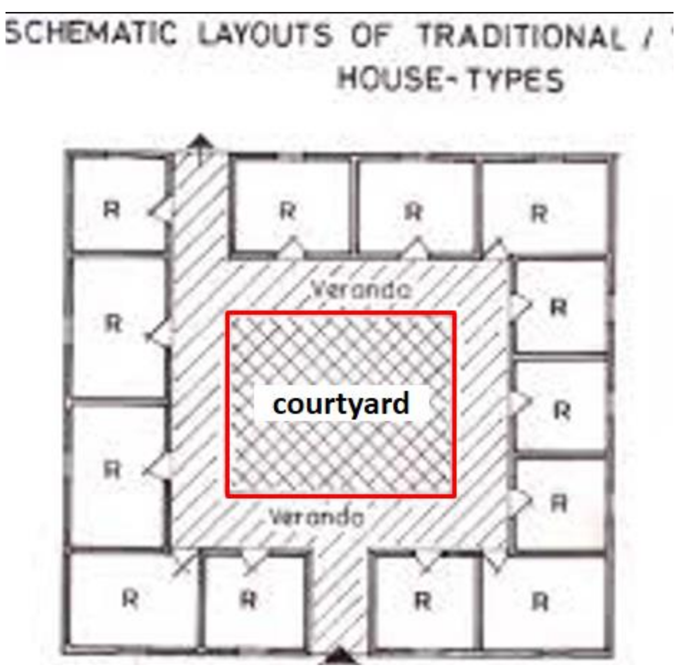

Figure 2: Schematic Layout of a Traditional Compound House Showing Central Courtyard (Typical Vernacular Design in Hot Climates, Applicable to Hausa Architecture)

Comparative studies confirm that traditional Hausa homes outperform many modern counterparts in thermal performance and resource efficiency, offering valuable lessons for hybrid applications using stabilized earth blocks or reinforced traditional techniques (Noma, 2022; exploring the sustainable features of Hausa architecture, 2025) has been presented in Table 4.

Table 4: Comparison of Key Bioclimatic Design Elements in Traditional Hausa and Modern Buildings in Hot-Dry Climates

Design Element	Traditional Hausa Features	Modern Conventional Features	Reported Benefits (Thermal/Comfort/Energy)	Key Sources
Orientation	North-south long axis; courtyards for shading	Often arbitrary or east-west dominant	Minimizes solar gain; 20–30% potential cooling load reduction	Abubakar (2014)
Thermal Mass	Thick mud/tubali walls (high thermal lag)	Thin sandcrete/concrete blocks	Indoor temperature drop of 4–6°C; stabilizes diurnal swings	Keeping Cool Under the Hot Arewa Sun (2022); Noma (2022)
Ventilation	Central courtyards; stack effect; small high openings	Limited or mechanical-dependent	Natural cross/stack ventilation; improved comfort without AC	Abubakar (2014); Tal (2022)
Shading & Openings	Verandas, overhangs, small windows with shutters	Large glazed windows; minimal shading	Reduces glare and heat gain; better daylight control	Abubakar (2014)
Materials	Earthen blocks, thatch, low-embodied energy	Cement-based blocks, concrete roofs	Lower embodied carbon; better passive performance	Noma (2022)

Sources: Abubakar (2014); Noma (2022); Tal (2022).

Sustainable Architectural Practices and Passive Strategies in Hot-Dry Climates

As previously shown in Tables 2 and 4, evidence-based strategies suitable for Katsina include:

1. Orientation and Massing: Elongated east-west axes and compact courtyard forms to minimize solar exposure (Abubakar, 2014).
2. Shading and Ventilation: Overhangs, verandas, and strategic openings for natural airflow.
3. Thermal Mass and Materials: Exposed earth or concrete mass combined with reflective roofing; stabilized soil blocks as affordable, low-carbon alternatives.
4. Microclimate Enhancement: Native vegetation for shading and windbreaks.
5. Water Management: Rainwater harvesting and elevated foundations for flood resilience (Unegbu, 2024; Hassan et al., 2023).

Simulations in northern Nigerian contexts suggest cooling load reductions of 20–50% through integrated passive measures (Alegbe et al., 2025; Abubakar, 2014). Emerging approaches like green roofs, solar integration, and building information modeling (BIM) remain limited in adoption.

Barriers to Adoption of Sustainable Practices

Major barriers identified in Nigerian studies (with direct relevance to Katsina) include lack of understanding of green technologies (relative importance index [RII] 0.79), absence of dedicated policies and institutions (RII 0.77), scarcity of sustainable materials and equipment (RII 0.76), and poor stakeholder collaboration, as depicted in Table 5 (Agboola et al., 2023). Additional challenges encompass preference for conventional methods, skills gaps among professionals, weak regulatory enforcement, and perceived high upfront costs (Unegbu, 2024; Amasuomo, n.d.). In Katsina, these are compounded by arid logistics for material sourcing and limited localized research capacity.

Table 5: Barriers to Sustainable Green Building Practice in Nigeria Ranked by Relative Importance Index (RII)

Rank	Barrier	RII	Implications for Hot-Dry Climates in Katsina State
1	Lack of understanding of green building technologies	0.79	Limits adoption of passive cooling and vernacular-hybrid designs
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4	Poor stakeholder collaboration & communication	0.76	Hinders integration of architects, clients, and local masons
5	Preference for conventional practices & long approval processes	0.75–0.76	Perpetuates high-energy concrete designs despite flood/heat risks

Source: Agboola et al. (2024).

Policy and Institutional Context

Nigeria's National Building Code and Katsina State Housing Policy (2024) emphasize resilience, sustainability, and climate-responsive development, including domestication of codes for green construction and integration of flood risk management (Katsina State Government, 2024). However, implementation remains inconsistent. Initiatives such as community resilience workshops and infrastructure projects provide opportunities for mainstreaming sustainable design (Unegbu, 2024).

Discussion and Research Gaps

While traditional Hausa knowledge offers a robust foundation for climate-responsive design, empirical post-occupancy evaluations (POE) and long-term thermal monitoring studies specific to Katsina State remain remarkably scarce. Most available evidence still relies heavily on computer modeling (Alegbe et al., 2025), single-building design theses such as the proposed FUDMA Senate Building (Abubakar, 2014), or extrapolations from nearby regions like Kano City, where vernacular strategies have been more extensively documented (Tal, 2022; Keeping Cool Under the Hot Arewa Sun, 2022). This dependence on simulated or analog data limits the ability to validate real-world performance under Katsina's unique microclimatic conditions, including intense harmattan dust, extreme diurnal temperature swings, and localized flooding patterns.

Key research gaps persist across multiple dimensions. First, there is a notable absence of comprehensive life-cycle assessments (LCA) for hybrid materials that combine traditional stabilized earth blocks or tubali with modern reinforcements. While studies highlight the superior thermal performance and low embodied energy of indigenous materials (Noma, 2022; exploring the sustainable features of Hausa architecture, 2025), few quantify long-term durability, maintenance costs, or environmental trade-offs under accelerating climate stressors in Katsina. Similarly, community perceptions of vernacular revival, particularly residents' willingness to adopt or retrofit with courtyard typologies, thermal mass walls, or passive ventilation features have received minimal attention. Emerging work on the psychological impacts of architectural aesthetics in Katsina suggests that culturally resonant designs enhance urban well-being and sense of place (Gidado, n.d.), yet these insights are rarely linked to thermal comfort or energy performance outcomes.

A second critical gap lies in integrated urban-scale resilience planning. Current literature tends to focus on individual buildings or isolated institutional projects (e.g., university buildings in Dutsin-Ma), with little examination of how building design interacts with broader urban sprawl, land-use patterns, and infrastructure. Rapid expansion of built-up areas in Dutsin-Ma and Katsina metropolis has increased impermeable surfaces, exacerbating runoff and flood vulnerability in wards such as Makera South, Garhi East, and Sakarya (Hassan et al., 2023). Poor urban planning, ineffective development control, and illegal constructions further compound these risks, leading to structural failures, road blockages, and socio-economic disruptions during flood events (Hassan et al., 2023; Charanchi, 2024). Studies on reinforced concrete failures in Katsina residential buildings point to issues like poor material quality, inadequate foundations, and overloading, which undermine safety and longevity in the hot-dry climate (Sabi'u, 2021). However, there remains limited research on how these micro-level design flaws scale up to macro-level urban resilience challenges.

Third, quantitative validation of flood-resilient prototypes, such as elevated foundations, integrated drainage systems, permeable surfaces, or hybrid vernacular-modern housing is very much underdeveloped. While flood impact assessments in Dutsin-Ma document significant property damage and call for relocation, better drainage, and zoning (Hassan et al., 2023; Abdulmajid, 2023), few studies test or monitor the performance of climate-adaptive design interventions in real occupied buildings. Post-occupancy evaluations, which are standard in more developed contexts for assessing thermal comfort, indoor environmental quality, and user satisfaction, are only beginning to emerge in northern Nigeria and are virtually absent in Katsina-specific literature (Ugochukwu, 2025; Olaiya, 2025 on bioclimatic principles in Katsina hospitals).

Climate projections intensify the urgency of addressing these gaps. Recent analyses show significant warming trends in Katsina, with minimum and maximum temperatures rising and inter-annual rainfall variability contributing to both drought stress and intense flooding events (Ahmad et al., 2023). Desertification risk exhibits a clear north-south gradient, with northern local government areas facing exceptional vulnerability due to vegetation loss linked to higher temperatures and erratic precipitation. Without localized empirical data, architects and policymakers risk promoting generic "sustainable" solutions that fail to perform under these evolving conditions or that overlook cultural and socio-economic realities.

Additional gaps include the limited exploration of health co-benefits (e.g., reduced heat stress, lower indoor radon or radiation exposure from building materials) (Gambo, 2025), economic modelling of retrofit versus new-build costs, and the role of stakeholder engagement in overcoming adoption barriers (Agboola et al., 2023; Amasuomo, n.d.). Green building strategies tailored to north-western Nigeria's hot-dry zone have been proposed via Delphi methods, yet implementation studies and performance monitoring lag behind (relevant Delphi study on green strategies, 2024). Broader regenerative or bioclimatic frameworks for Nigerian buildings also highlight the need for context-specific adaptations rather than imported models (Agboola et al., 2024; Olaiya, 2025). We can therefore infer that, the current body of knowledge provides a strong conceptual foundation rooted in Hausa vernacular wisdom but falls short in delivering actionable, evidence-based guidance for Katsina State. Bridging these gaps through rigorous, mixed-methods research, combining field monitoring, POE, LCA, community surveys, and GIS-based urban modelling will indeed be essential. Such efforts would not only strengthen climate resilience but also support culturally sensitive, low-carbon development that aligns with Nigeria's sustainable development goals and national building code aspirations. Table 6 summarizes the major research gaps identified across the reviewed literature.

Table 6: Key Research Gaps in Building Design and Climate Resilience Studies for Katsina State

Gap Category	Description	Why Critical	Recommended Approach
Empirical Monitoring	Lack of long-term POE and thermal monitoring	Reliance on modeling limits real-world validation	Field measurements + sensors
Life-Cycle Assessment (LCA)	Few assessments of hybrid earth-concrete materials	Unknown long-term sustainability & costs	LCA studies on stabilized blocks
Urban-Scale Integration	Limited linkage of building design to sprawl/flood planning	Exacerbates city-wide vulnerability	GIS + multi-scale modeling
Community Perceptions & Flood Prototypes	Minimal data on resident acceptance or tested resilient designs	Risk of culturally inappropriate solutions	Participatory surveys + pilot projects

Recommendations Toward Climate-Resilient Practices

1. Develop Katsina-specific design guidelines that integrate Hausa passive principles with modern tools for thermal comfort, flood resilience, and low-carbon materials.
2. Update and enforce building codes to mandate climate-responsive features such as optimal orientation, shading, and elevated foundations (Katsina State Government, 2024).
3. Invest in capacity building for architects, engineers, and local masons through curricula at institutions like FUDMA and practical training in hybrid techniques.
4. Fund localized research, including thermal monitoring, demonstration projects in flood-prone wards, and economic analyses of sustainable retrofits.
5. Promote participatory design processes that respect cultural values and raise public awareness.
6. Encourage material innovation, such as scaled production of stabilized earth blocks, to reduce costs and import dependency.

CONCLUSION

Building design in Katsina State plays a decisive role in determining whether the built environment amplifies climate vulnerabilities or strengthens resilience and sustainability. Traditional Hausa architecture demonstrates time-tested, low-technology solutions that have been largely overlooked in contemporary practice, resulting in significant environmental, social, and economic costs. Modern concrete-dominated designs often exacerbate indoor overheating, increase energy demands, heighten flood vulnerability, and contribute to the erosion of cultural identity. A deliberate shift toward hybrid, climate-responsive, and culturally sensitive architectural practices offers a viable pathway forward. By thoughtfully integrating passive cooling strategies, thermal mass principles, natural ventilation, flood-resilient features, and locally adapted materials, buildings in Katsina State can achieve substantial reductions in energy consumption while delivering greater thermal comfort, safety, and long-term affordability. Such approaches also provide opportunities to preserve Hausa architectural heritage and support local skills and economies. Achieving this transformation requires coordinated action among architects, policymakers, researchers, and local communities. Updated building codes that prioritize climate-responsive design, targeted capacity-building programs for professionals and artisans, demonstration projects that showcase hybrid solutions, and sustained public awareness efforts are essential. Ultimately, embedding indigenous knowledge within modern sustainable frameworks will enable Katsina State to develop a built environment that is not only resilient to rising temperatures, erratic rainfall, and desertification pressures but also culturally grounded and environmentally responsible. This review underscores that the future of architecture in hot-dry regions like Katsina lies in bridging the wisdom of the past with the innovations of the present. With urgent and collaborative effort, Katsina State can lead the way toward low-carbon, climate-resilient, and culturally vibrant built environments that serve both current and future generations.

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