# Comparative Analysis of Passive Retrofit Strategies for Thermal Comfort Improvement in Public Library in Abuja

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***Abstract***
*Public buildings in Nigeria's rapidly urbanising cities increasingly depend on mechanical cooling to maintain habitable conditions, a costly, energy-intensive approach poorly suited to a strained national grid. This study examines passive design strategies as a climate-responsive alternative for enhancing thermal comfort in public library buildings within Abuja's tropical savanna (Aw) climate. A mixed-methods design combined qualitative case study analysis of three institutional libraries — Murtala Muhammed Library, Kano; the Ibrahim Badamasi Babangida Library, FUTMINNA; and the Surry Hills Library and Community Centre, Sydney — with quantitative building performance simulation. The Bingham University Library Reading Hall, Karu, was modelled in DesignBuilder using the EnergyPlus engine and an Abuja Typical Meteorological Year dataset as an unoptimised baseline, against which five passive interventions were tested sequentially: orientation optimisation, solar shading, natural and night ventilation, thermal mass enhancement, and roof insulation with reflective coating. Cumulative application of these measures reduced the Predicted Percentage of People Dissatisfied from 97 percent to 11 percent and compressed peak indoor temperature from 40.1°C to 29.8°C. Solar shading and night-purged ventilation produced the largest individual gains. The study concludes that synergistic passive design offers Nigerian institutional architecture a viable route to comfortable, low-energy public buildings.*

**Keywords:** *Passive design, Thermal comfort, Public libraries, Building performance simulation, Abuja, Tropical savanna climate*

## 1.0 Introduction

The continuous expansion and urbanisation of African cities has heightened concern for sustainable building design, particularly in regions with demanding climatic conditions such as Abuja, Nigeria's Federal Capital Territory. As the city has grown into a major administrative and cultural hub, demand for public facilities such as libraries, learning centres and civic spaces has risen sharply, and with it, energy consumption for cooling and ventilation. Abuja's tropical climate, characterised by high solar radiation, elevated daytime temperatures and extended dry seasons, poses substantial challenges to achieving thermal comfort without over-reliance on mechanical systems (Adeleke & Olanrewaju, 2022). In public buildings such as libraries, where user comfort underpins productivity and sustained learning, reconciling thermal comfort with energy efficiency is a critical design objective. Passive design strategies offer a sustainable, contextually appropriate response to this challenge. Passive design integrates architectural elements and natural environmental factors solar orientation, natural ventilation, shading, thermal mass and material selection to achieve comfortable indoor conditions with minimal mechanical intervention (Olanipekun & Okafor, 2021). In hot-dry and tropical regions, interventions such as cross ventilation, shading louvres, optimised orientation, green roofs and locally sourced materials have been shown to lower indoor temperatures and improve occupant satisfaction significantly (Hassan & Alawode, 2022), while evaporative cooling and courtyards have proven effective at mitigating heat accumulation in educational and public buildings (Zhao et al., 2021). Despite this evidence, the integration of passive design strategies in Nigerian public architecture remains limited: many public libraries are designed with little regard for climatic responsiveness, resulting in excessive heat gain, poor ventilation and high energy consumption (Okonkwo, 2024).

Energy use in public buildings across Nigeria continues to rise, with cooling and ventilation accounting for over 60 percent of total building energy consumption (Adeleke & Olanrewaju, 2022). In Abuja, where high solar radiation, elevated ambient temperatures and long dry seasons dominate, libraries and similar civic buildings often rely heavily on mechanical cooling to sustain indoor comfort, a dependency that drives up operational costs, strains the national grid and increases greenhouse gas emissions (Okonkwo, 2024). Many of these buildings also incorporate non-adaptive design features poor orientation, inadequate cross ventilation, minimal shading leading to overheating that undermines both occupant wellbeing and the case for passive alternatives (Alawode & Hassan, 2023). There remains, moreover, limited local research quantifying how effectively specific passive strategies improve thermal comfort within Abuja's hot-dry tropical climate, restricting the availability of evidence-based benchmarks for architects and engineers designing in the region (Olanipekun & Okafor, 2021).

Against this background, this study evaluates the performance of passive design strategies building orientation, solar shading, natural ventilation, thermal mass and roof treatment in enhancing thermal comfort for public library design in Abuja, and translates the resulting evidence into design guidance for climate-responsive public architecture in Nigeria.

### 1.1 Theoretical Framework

Two theoretical positions frame the analysis. Bioclimatic design theory holds that architecture should be shaped in direct response to climate in order to reduce energy use and enhance comfort, promoting strategies such as orientation, shading and natural ventilation as first-order design decisions rather than afterthoughts (Adeleke & Olanrewaju, 2022). High-performance building envelope theory, in turn, emphasises the role of walls, roofs, glazing and insulation in regulating heat flow, positioning a well-designed envelope as essential in highly solar-exposed regions such as Abuja (Zhao et al., 2021). Together, these theories provide the conceptual base for assessing passive design effectiveness in public libraries, and they align with recognised thermal comfort standards ASHRAE Standard 55 and ISO 7730 which define the neutral comfort zone against which the study's simulation outputs are validated (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020; ISO, 2005).

## 2.0 Methodology

This study adopts a mixed-methods, convergent design combining qualitative case study analysis with quantitative building performance simulation (BPS). The qualitative component draws on purposively selected institutional and civic library precedents to ground the research in built architectural realities, while the quantitative component uses dynamic thermal simulation to model and test the performance of discrete passive interventions under Abuja's climate (Creswell & Creswell, 2021).

Three case study libraries were purposively selected on the basis of climatic alignment, functional similarity and the documented presence of passive design features: the Murtala Muhammed Library, Kano (tropical savanna, BSh); the Ibrahim Badamasi Babangida (IBB) Library, Federal University of Technology, Minna, Niger State (hot and humid to semi-arid transitional climate); and the Surry Hills Library and Community Centre, Sydney, Australia, included as an international high-performance benchmark for climate-adaptive envelope technology. Each case was assessed for spatial layout, massing, material palette, landscape integration and the resulting merits and demerits for thermal performance.

For the quantitative component, the Bingham University Library Reading Hall, Karu, Nasarawa State a single-storey, approximately 960 m² institutional reading space operating eight hours daily and typifying conventional Nigerian institutional library construction was modelled in DesignBuilder with the EnergyPlus simulation engine, driven by a verified hourly Typical Meteorological Year (TMY) dataset for Abuja (NiMet, 2023). The unoptimised configuration (diagonal orientation, unshaded single glazing, sealed envelope, minimal thermal mass, uninsulated flat concrete roof) served as the baseline against which five passive design strategies were tested sequentially and cumulatively: orientation optimisation, solar shading devices, natural and night ventilation, thermal mass enhancement, and roof insulation with reflective coating. Outputs indoor operative temperature, roof surface temperature, and Predicted Mean Vote (PMV) and Predicted Percentage of People Dissatisfied (PPD) indices were exported and compared against the baseline and against ASHRAE 55 / ISO 7730 comfort thresholds (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020; ISO, 2005), allowing the predictive simulation data to be cross-validated against the qualitative, case-study-derived understanding of how these same strategies perform in practice.

## 3.0 Discussion of Findings

This section presents the study's findings under four themes: the determinants of thermal comfort relevant to library spaces, the passive design strategies available to address them, lessons drawn from local and international case studies, and the simulation-based evidence quantifying their performance in Abuja's climate.

### 3.1 Thermal Comfort Determinants in Public Library Design

Thermal comfort is determined by six interacting environmental and personal variables: air temperature, relative humidity, mean radiant temperature, air movement, clothing insulation and metabolic rate (Fanger, 1970; American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020). In Abuja, ambient dry-season temperatures and low relative humidity intensify the effect of solar-driven mean radiant temperature in poorly shaded, poorly insulated buildings, while the low metabolic rates associated with sedentary reading and study activities mean that library occupants require more stringent thermal control than occupants of more active building types (Fanger, 1970). Because public libraries serve diverse user groups students, researchers, children and older adults over extended, often full-day periods, sustained thermal discomfort translates directly into reduced cognitive focus, reading retention and overall productivity, underscoring the practical stakes of passive design decisions in this building type (Mendell & Heath, 2005; Wyon, 2004).

### 3.2 Passive Design Strategies for Tropical Public Buildings

Evidence from the literature and from this study's simulation confirms that the strategic combination of the following passive measures is central to achieving thermal comfort in tropical public buildings:

**i. Building Orientation:** Orienting a building's long axis north–south minimises exposure to the harsh low-angle east and west sun. It is a zero-cost intervention that suppresses baseline radiant heat loads and amplifies the effectiveness of subsequent shading and ventilation measures (Givoni, 1994).

**ii. Solar Shading and Control:** Overhangs, louvres, vertical fins, brise-soleil and pergolas intercept direct solar radiation before it reaches glazed openings, substantially reducing internal heat gain and glare (Okonkwo, 2024).

**iii. Natural Ventilation:** Cross and stack ventilation, supported by operable openings and night-flush strategies, purges accumulated heat and moderate's humidity, and is particularly effective where diurnal temperature swings allow cool night air to pre-cool the building's mass (Hassan & Bello, 2023).

**iv. Thermal Mass:** Dense materials such as concrete, rammed earth and stone absorb heat during the day and release it slowly at night, delaying peak heat transmission into cooler evening hours when it can be more easily vented (Adewuyi, 2021).

**v. Courtyards and Green Landscaping:** Courtyard geometry and vegetation create cool microclimates through shading and evapotranspiration, with documented reductions in ambient temperature of 4–6°C, while also enhancing daylighting and natural ventilation (UN Habitat, 2023).

**vi. Roof Insulation and Reflective Coatings:** Because the roof absorbs the greatest share of solar radiation in single- and low-storey tropical buildings, high-albedo reflective coatings and insulation with high R-values are critical for limiting conductive and radiant heat transfer into occupied space below (Zhao et al., 2021).

### 3.3 Lessons from Local and International Case Studies

The three case studies illustrate a clear performance gradient linked to the deliberateness of passive design integration. The Murtala Muhammed Library, Kano, an east–west-oriented, post-independence modernist block with an uninsulated flat roof reaching over 55°C in the dry season and no dedicated shading devices, relies almost entirely on high ceilings and mechanical fans to manage heat, illustrating the performance limitations of institutional buildings designed without climatic responsiveness. The IBB Library, FUTMINNA, demonstrates a more deliberate approach: an integrated central courtyard drives stack-effect cooling and daylighting, and vertical fins and buttress-like projections provide structural shading, but uninsulated corrugated roofing over parts of the building and deep floor plates limit the consistency of these gains. The Surry Hills Library and Community Centre, Sydney, represents the upper bound of technological sophistication, combining automated solar-tracking louvres, a subterranean thermal labyrinth and a green-roofed bio-filtration atrium to cut mechanical cooling loads by close to half at a cost and maintenance burden that also flags the limits of directly transplanting such systems into a Nigerian public-sector context.

**Table 1: Comparative Overview of Case Study Libraries**

| Case Study | Location / Climate | Key Passive Features | Key Limitation |
|---|---|---|---|
| Murtala Muhammed Library | Kano, Nigeria (BSh) | East–west reading hall, high ceilings promoting stack effect, light-coloured render | Uninsulated flat roof (>55°C surface), no shading devices, minimal vegetation |
| IBB Library, FUTMINNA | Niger State, Nigeria (transitional semi-arid) | Central bioclimatic courtyard, vertical shading fins, heavy masonry walls | Uninsulated corrugated roof sections, deep plan limits cross-ventilation |
| Surry Hills Library & Community Centre | Sydney, Australia (temperate) | Automated solar-tracking louvres, subterranean thermal labyrinth, green roof and bio-filters | High capital and maintenance cost; ventilation less effective in extreme heat |

*Source: Author's case study analysis (2026).*

### 3.4 Simulation-Based Performance Evaluation of Passive Interventions

The baseline simulation of the Bingham University Library Reading Hall revealed severe thermal inadequacy under Abuja's climate: an unshaded, partly sealed envelope produced a pronounced greenhouse effect, with an annual mean operative temperature of 35.4°C, a peak dry-season mean of 38.2°C, an absolute peak of 40.1°C, and a corresponding PPD of 97 percent meaning the space was thermally unsatisfactory for almost the entire occupant population. Five passive strategies were then introduced sequentially, each building on the last.

Reorienting the building from its diagonal baseline to a north–south axis (Strategy 1) reduced the annual mean to 33.6°C and the PPD to 88 percent a modest but cost-free gain that lowered the baseline for subsequent interventions. Adding vertical shading fins at 600 mm spacing (Strategy 2) produced the single largest improvement, cutting the annual mean to 31.2°C and the PPD to 58 percent, confirming solar exclusion as the dominant lever in this climate. Introducing operable openings, a clerestory ridge vent and night-flush ventilation (Strategy 3) brought the annual mean down to 29.4°C and the PPD to 32 percent, with the diurnal swings of the dry season making night purging especially effective. Upgrading wall and floor construction to increase thermal mass (Strategy 4) delayed peak heat transmission by four to five hours and reduced the annual mean to 28.6°C, with the peak-season mean falling to 31.8°C. Finally, insulating the roof and applying a high-albedo reflective coating (Strategy 5) cut roof surface temperature from 54.3°C to 31.8°C a reduction of 22.5°C and brought the annual mean to 27.8°C, with peak indoor temperature reduced to 30.4°C.

**Table 2: Stepwise Simulation Results Bingham University Library Reading Hall**

| Scenario | Intervention | Annual Mean Temp. (°C) | Hot Season Mean (°C) | PPD (%) |
|---|---|---|---|---|
| Baseline | Unoptimised (as-built) configuration | 35.4 | 38.2 | 97 |
| S1 | North–south orientation optimisation | 33.6 | 36.0 | 88 |

| Scenario | Intervention | Annual Mean Temp. (°C) | Hot Season Mean (°C) | PPD (%) |
|---|---|---|---|---|
| S2 | + Vertical solar shading fins (600 mm) | 31.2 | 32.8 | 58 |
| S3 | + Natural ventilation with night flushing | 29.4 | 31.5 | 32 |
| S4 | + Thermal mass enhancement (walls & floor) | 28.6 | 30.1 | 22 |
| S5 | + Roof insulation & reflective coating | 27.8 | 29.6 | 16 |
| Integrated | All five strategies combined | 27.1 | 28.4 | 11 |

*Source: DesignBuilder / EnergyPlus simulation, Abuja TMY dataset (2026).*
Combining all five strategies into a single integrated model produced a complete stabilisation of internal thermal behaviour: the PPD fell from 97 percent at baseline to 11 percent, placing the space within the neutral comfort parameters of ASHRAE Standard 55 and ISO 7730 (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020; ISO, 2005), and the absolute peak indoor temperature during the April dry-season peak was compressed from an unliveable 40.1°C to a safe, focused 29.8°C. Individually, shading devices delivered the largest single reduction (2.4°C), aligning with established solar-exclusion logic for the sub-Saharan belt, while thermal mass and roof treatment were most effective not at lowering annual means but at suppressing extreme peaks, which matters disproportionately for an activity  sustained reading  that is highly sensitive to short episodes of severe overheating. The overall pattern confirms that no single passive measure is sufficient on its own; it is the compounding, synergistic interplay of orientation, shading, ventilation, mass and envelope insulation that decouples a high-occupancy public facility from a hostile tropical climate without mechanical support.

**3.5 Obstacles to Passive Design Adoption in Nigerian Public Architecture**
**i. Weak Enforcement of Climate-Responsive Design Standards:** guidance exists in principle, but many public buildings are procured and approved with little scrutiny of orientation, shading or envelope performance (Olanipekun & Okafor, 2021).

**ii. Scarcity of Localised Performance Data:** most empirical passive design research centres on temperate or humid-tropical regions, leaving Abuja's specific diurnal swings and seasonal dust challenges under-studied and limiting the availability of local design benchmarks (Falade, 2011; Obi & Ubani, 2022).

**iii. Cost-Driven Design Decisions:** passive features such as shading systems, insulation and high-performance glazing are frequently treated as discretionary costs rather than integral to building performance, especially in publicly funded projects (Adeyemi et al., 2023).

**iv. Limited Use of Simulation in Local Practice:** the scarcity of studies using building performance simulation for predictive thermal modelling in Nigerian contexts restricts the evidence base architects can draw on when justifying passive interventions to clients (Ogundipe & Balogun, 2023).

v. **Persistence of Non-Adaptive Design Conventions:** modernist blocks with unshaded glazing, poor orientation and uninsulated roofs remain a default typology, as seen in the Murtala Muhammed Library case study, despite decades of evidence of their thermal shortcomings (Alawode & Hassan, 2023).

## 4.0 Conclusion

This study set out to evaluate how passive design strategies can be integrated to enhance thermal comfort in the design of a public library in Abuja's tropical savanna climate. Combined case study and simulation evidence shows that orientation, solar shading, natural ventilation, thermal mass and roof treatment each contribute measurable, cumulative reductions in indoor operative temperature and occupant dissatisfaction, and that their synergistic combination can move a severely uncomfortable baseline space (97 percent PPD) into full compliance with recognised adaptive comfort thresholds (11 percent PPD) without mechanical cooling. The persistence of non-adaptive design conventions in existing Nigerian institutional libraries, set against the demonstrated performance of a fully integrated passive strategy, underscores both the scale of the current gap and the practicality of closing it. Addressing this gap requires coordinated effort among architects, engineers, regulators and public-sector clients to embed climate-responsive design as a default rather than an optional upgrade in the delivery of public buildings across Nigeria's hot-dry regions.

## 5.0 Recommendations

Based on the findings of this study, the following recommendations are put forward:

**A. Recommendations for Architects and Built Environment Professionals**

i. Prioritise north–south building orientation at the earliest concept stage, as a zero-cost intervention that improves the effectiveness of every subsequent passive measure.

ii. Specify solar shading devices fins, louvres, overhangs or brise-soleil on all east- and west-facing glazing in public building design, given their outsized contribution to comfort in this climate.

iii. Design for natural and night-flush ventilation wherever security and acoustic requirements permit, to exploit Abuja's pronounced diurnal temperature swings.

iv. Use building performance simulation routinely at design stage to quantify and justify passive interventions to clients, rather than relying on convention alone.

**B. Recommendations for Government, Policy Makers and Institutions**

i. Integrate minimum passive design and envelope-performance requirements into building approval processes for publicly funded libraries and civic buildings.

ii. Allocate dedicated budget lines for passive envelope measures insulation, shading, reflective roofing in public building procurement, rather than treating them as the first items cut under cost pressure.

iii. Support the development of local, freely accessible climate and building performance datasets to reduce the barrier to simulation-based design in Nigerian practice.

iv. Commission post-occupancy evaluation of existing public buildings to build a local evidence base of passive design performance across Nigeria's diverse climatic zones.

## 5.1 Contribution to Knowledge

This study contributes a locally grounded, simulation-validated performance dataset for passive design strategies in Nigerian public library architecture, a building typology that has received limited targeted attention relative to residential and general commercial buildings. By quantifying the individual and cumulative thermal contribution of five discrete passive interventions against a real, representative Nigerian institutional baseline, and by triangulating this quantitative evidence with qualitative case study analysis across local and international precedents, the study provides architects, regulators and researchers with an evidence-based reference framework for the design of climate-responsive, low-energy public buildings in Abuja and comparable tropical savanna contexts

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