Daylighting Design Strategies for Energy Maximization in Public Buildings in Hot Tropical Climate

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Abstract: Public buildings in hot tropical climates are typically characterized by high daytime occupancy and sustained dependence on artificial lighting and mechanical cooling, resulting in significant operational energy demand. In cities such as Makurdi, where solar availability is high but thermal control is critical, daylighting presents both an opportunity for electrical load reduction and a risk of increased cooling energy if poorly integrated. This paper investigates daylighting as a passive design strategy for energy maximization in public buildings within Makurdi's hot tropical climate. The study evaluates the performance of key daylighting design variables, including building orientation, plan depth, window-to-wall ratio, shading configuration, and sectional articulation, in relation to both lighting energy demand and cooling load. Climate-based daylight metrics are employed alongside energy performance simulations to assess daylight autonomy, glare potential, and thermal implications under local climatic conditions. Rather than maximizing daylight levels indiscriminately, the analysis focuses on identifying spatial configurations that achieve useful daylight while limiting solar heat gain. Findings demonstrate that controlled daylighting strategies, particularly those combining shallow plan depths with external shading and optimized aperture placement, can significantly reduce reliance on artificial lighting without incurring proportional increases in cooling demand. The paper argues that daylighting effectiveness in hot tropical public buildings is contingent on its integration within a broader passive design framework rather than its treatment as an isolated environmental feature. The study contributes climate-specific evidence to sustainable public building design discourse and offers design-relevant insights for energy-conscious daylighting in hot tropical urban environments.

Keywords: *Daylighting Design; Energy Maximization; Public Buildings; Hot Tropical Climate; Passive Design Strategies; Cooling Load Reduction; Climate-Based Daylight Metrics; Makurdi.*

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I. INTRODUCTION

➢ *Background and Problem Statement*

Public buildings in hot tropical climates are among the most energy-intensive components of the urban built environment due to extended daytime occupancy, high internal loads, and sustained dependence on mechanical cooling and artificial lighting systems (Zacki & Pathirana, 2025, IEA, 2019; Pérez-Lombard, Ortiz, & Pout, 2008). In such climates, solar availability is abundant throughout the year, presenting significant potential for daylight utilization. However, this same solar resource also constitutes a primary driver of indoor heat gain, particularly when building envelopes are inadequately designed to mediate radiation and glare (Lamberts, Dutra, & Pereira, 2014, Adua et al., 2024).

Daylighting has long been promoted as a passive strategy capable of reducing electrical lighting demand while improving visual comfort and spatial quality (Reinhart & Wienold, 2011, Nasrollahi & Shokri, 2016, Monzavi et al., 2026). Yet in hot tropical regions, the relationship between daylight admission and overall energy performance is structurally conflicted. Increased aperture size, inappropriate orientation, and unshaded glazing may reduce lighting energy consumption while simultaneously elevating cooling loads, often resulting in net increases in total operational energy use (Al-Shaibani, Al-Mumin, & Al-Hajj, 2020). Consequently, daylighting cannot be treated as an isolated environmental feature but must be evaluated as part of an integrated thermal–visual energy system.

Makurdi, located within Nigeria's hot tropical climatic zone, exemplifies this tension. The city experiences high levels of solar radiation combined with elevated ambient temperatures for most of the year, making thermal control a dominant concern in public building performance. Despite this, many public buildings in Makurdi continue to rely heavily on artificial lighting during daytime hours, suggesting underutilization or poor integration of available daylight resources. Where daylighting strategies are present, they are

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frequently applied without sufficient consideration of their thermal consequences, leading to increased cooling demand and occupant discomfort.

This condition exposes a critical design and performance problem: how daylighting strategies can be configured to meaningfully reduce lighting energy demand in public buildings within hot tropical climates without triggering disproportionate increases in cooling energy. Addressing this problem requires a shift from maximizing daylight quantity toward optimizing useful daylight under climatic constraint.

➢ *Research Gap*

Existing daylighting research is disproportionately concentrated in temperate and cold climates, where heating demand often dominates and solar gains are largely beneficial (Reinhart & Walkenhorst, 2001; Heschong et al., 2005, Hu et al., 2023, Ramezani et al., 2026). Studies conducted in tropical contexts frequently evaluate daylight performance independently of cooling energy implications or rely on static illuminance targets that fail to capture climatic variability and occupant exposure over time (Mangkuto, Rohmah, & Asri, 2016, Setiawan & Elsiana, 2025).

Moreover, many simulation-based studies prioritize high daylight autonomy values as indicators of success without adequately interrogating the associated thermal penalties imposed by solar radiation through building envelopes. This methodological separation limits the applicability of findings to hot tropical public buildings, where cooling energy often exceeds lighting energy by a significant margin (Santamouris et al., 2018, Kamel et al., 2024, Baharuddin et al., 2025, Sherif et al., 2025). There remains a lack of climate-specific, integrative studies that simultaneously assess daylight availability, visual comfort, and cooling load within the same analytical framework for public buildings in hot tropical cities such as Makurdi. This gap constrains the development of evidence-based daylighting strategies that are both energy-efficient and thermally appropriate.

➢ *Aim and Objectives*

The aim of this study is to evaluate daylighting as a passive design strategy for energy maximization in public buildings within Makurdi's hot tropical climate by examining its combined effects on lighting energy demand and cooling load.

- *The Specific Objectives are to:*

✓ Assess the daylight performance of key architectural design variables, including building orientation, plan depth, window-to-wall ratio, shading configuration, and sectional articulation, using climate-based daylight metrics.
✓ Quantify the impact of these daylighting strategies on cooling energy demand under local climatic conditions.
✓ Identify spatial and envelope configurations that achieve useful daylight while limiting excessive solar heat gain.
✓ Develop design-relevant insights for integrating daylighting within a broader passive energy framework for hot tropical public buildings.

➢ *Scope and Significance*

The study focuses on representative public building typologies within Makurdi and evaluates performance under local climatic data using simulation-based analysis. The scope is limited to operational energy associated with lighting and cooling, excluding embodied energy considerations. The significance of the study lies in its contribution to climate-specific architectural knowledge by demonstrating how daylighting effectiveness in hot tropical public buildings depends on controlled integration rather than indiscriminate daylight maximization. The findings are intended to inform architects, building engineers, and public sector decision-makers seeking energy-conscious design strategies suited to tropical urban environments.

II. LITERATURE REVIEW

➢ *Daylighting and Energy Performance in Hot Tropical Climates*

Daylighting has been extensively investigated as a passive strategy for reducing electrical lighting demand in buildings. In temperate and cold climates, empirical and simulation-based studies consistently report net energy benefits from increased daylight penetration, largely because solar gains offset heating demand while reducing artificial lighting loads (Reinhart & Herkel, 2000; Heschong et al., 2005, Hu et al., 2023, Monzavi et al., 2026). However, the transferability of these findings to hot tropical climates is limited due to fundamentally different thermal regimes.

In hot tropical regions, cooling energy dominates total operational energy consumption, particularly in public buildings characterized by high daytime occupancy and internal gains (Santamouris et al., 2018, Cárdenas-Rangel et al., 2023, Lim et al., 2026). Several studies have demonstrated that daylighting strategies which increase glazing area or solar exposure can lead to higher indoor temperatures and elevated cooling loads, often negating or surpassing the energy savings achieved through reduced electric lighting (Al-Obaidi, Ismail, & Abdul Rahman, 2014). This has led to growing recognition that daylighting effectiveness in tropical climates is contingent upon careful control of solar heat gain rather than maximization of daylight availability per se.

Research conducted in Southeast Asia, West Africa, and equatorial regions consistently emphasizes the importance of shading, orientation, and plan configuration in mediating the daylight–cooling trade-off (Kabanshi et al., 2023, Mangkuto et al., 2016; Wong & Istiadji, 2004). These studies suggest that shallow plan depths and well-shaded apertures can provide adequate daylight levels while limiting thermal penalties. Nevertheless, many such investigations focus on residential or office buildings, leaving public buildings underrepresented despite their distinct occupancy patterns and scale-related performance challenges.

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➢ *Climate-Based Daylight Metrics*

Traditional daylight evaluation methods relied heavily on static metrics such as daylight factor or fixed illuminance thresholds. While these measures are simple to apply, they fail to account for temporal variability in daylight availability and do not reflect actual occupant exposure under dynamic climatic conditions (Reinhart & Fitz, 2006, Hu et al., 2023, Monzavi et al., 2026). This limitation is particularly problematic in hot tropical climates, where solar intensity and sky conditions vary significantly throughout the day and year. Climate-based daylight metrics (CBDMs), including daylight autonomy and spatial daylight autonomy, were developed to address these shortcomings by integrating local climate data and time-based occupancy assumptions into daylight performance evaluation (Reinhart & Wienold, 2011). These metrics allow for a more realistic assessment of how often daylight levels meet functional requirements without artificial lighting.

However, while CBDMs offer substantial methodological advantages, their application in tropical contexts has been critiqued for insufficient integration with thermal performance analysis. High daylight autonomy values may indicate reduced lighting energy use but can simultaneously correspond to increased solar heat gains and glare risk if not evaluated alongside cooling load and visual comfort metrics (Mardaljevic, Heschong, & Lee, 2009). As a result, recent scholarship argues for the coupling of CBDMs with energy simulation to capture the full performance implications of daylighting strategies in hot climates (Al-Shaibani et al., 2020).

➢ *Daylighting Design Variables in Public Buildings*

Architectural daylighting performance is shaped by a constellation of interrelated design variables, including building orientation, plan depth, window-to-wall ratio, aperture placement, shading devices, and sectional configuration. In public buildings, these variables are further complicated by large floor plates, deep interior spaces, and diverse functional requirements.

Building orientation has been shown to significantly influence both daylight distribution and solar heat gain, with east- and west-facing facades posing particular challenges in tropical climates due to low-angle morning and afternoon sun (Olgyay, 2015). Plan depth plays a critical role in determining daylight penetration, as deeper plans often rely disproportionately on artificial lighting despite extensive glazing at the perimeter.

Window-to-wall ratio remains one of the most contested variables in daylighting design. While increased glazing generally improves daylight availability, studies in hot tropical regions indicate diminishing returns beyond moderate glazing percentages, accompanied by substantial increases in cooling demand (Mangkuto et al., 2016). External shading devices, such as horizontal overhangs and vertical fins, have been repeatedly identified as essential mediators that enable daylight admission while reducing direct solar radiation and glare (Al-Obaidi et al., 2014). Despite extensive analysis of individual variables, the literature frequently treats these elements in isolation, limiting the ability to derive integrated design strategies for public buildings. There is a need for studies that evaluate how combinations of daylighting variables interact under specific climatic conditions to influence both lighting and cooling energy performance.

➢ *Synthesis and Research Positioning*

The reviewed literature reveals three persistent limitations in daylighting research relevant to hot tropical public buildings. First, there is a methodological bias toward temperate-climate assumptions that overestimate the net energy benefits of increased daylight admission. Second, the widespread use of climate-based daylight metrics without concurrent thermal analysis risks misrepresenting performance outcomes in cooling-dominated contexts. Third, existing studies often isolate individual design variables rather than examining their combined spatial and energetic effects. This study positions itself at the intersection of these gaps by adopting an integrated analytical framework that evaluates daylighting strategies in relation to both lighting energy demand and cooling load within Makurdi's hot tropical climate. By focusing on public buildings and emphasizing design-relevant synthesis rather than metric optimization alone, the research seeks to advance a more context-sensitive understanding of daylighting as a component of passive energy design in tropical urban environments.

III. METHODOLOGY

➢ *Study Context and Climatic Characterization*

The study is situated in Makurdi, Nigeria, located within the hot tropical climatic zone characterized by high solar radiation, elevated ambient temperatures, and minimal seasonal temperature variation. Cooling demand dominates building energy consumption in this context due to persistently high outdoor temperatures and humidity levels throughout the year (Santamouris et al., 2018). These climatic conditions make Makurdi an appropriate case for evaluating the energy implications of daylighting strategies in public buildings where solar access is abundant but thermal control is critical.

Hourly climatic data for Makurdi were derived from a typical meteorological year (TMY) weather file, incorporating parameters such as global horizontal irradiance, direct normal irradiance, dry-bulb temperature, and relative humidity. The use of climate-based data enables dynamic assessment of daylight availability and thermal performance across annual occupancy cycles, consistent with best practices in building performance simulation (Reinhart & Fitz, 2006).

➢ *Building Typology and Model Definition*

A representative public building typology was adopted to reflect common spatial and functional characteristics observed in public facilities within Makurdi, including administrative and institutional buildings. The model consists of regularly occupied spaces with predominantly daytime use, where both artificial lighting and mechanical cooling are operational during working hours. The base model was defined using a rectilinear form to minimize geometric complexity and allow systematic variation of daylighting parameters. Internal loads, occupancy schedules, and equipment gains were assigned based on standard values reported in the literature for public buildings in tropical contexts (Pérez-Lombard et al., 2008). This approach ensures that observed performance differences can be attributed primarily to daylighting-related design variables rather than idiosyncratic programmatic effects.

➢ *Daylighting and Energy Simulation Tools*

Daylighting performance was evaluated using climate-based simulation techniques capable of calculating annual daylight availability under dynamic sky conditions. Climate-based daylight metrics, including daylight autonomy and spatial daylight autonomy, were employed to assess the proportion of occupied hours during which daylight levels meet predefined illuminance thresholds without artificial lighting (Reinhart & Wienold, 2011). Thermal and energy performance were assessed through whole-building energy simulation, allowing estimation of cooling energy demand associated with each daylighting configuration. Coupling daylight and energy simulations enables direct comparison between lighting energy savings and cooling energy penalties, an approach increasingly recommended for performance-based design evaluation in hot climates (Al-Shaibani et al., 2020). Simulation tools were selected based on their established validation in peer-reviewed research and their capacity to integrate daylighting and thermal analysis within a consistent modeling framework.

➢ *Daylighting Design Variables and Simulation Scenarios*

The study investigates a set of key daylighting-related design variables identified in the literature as having significant influence on both visual and thermal performance in hot tropical buildings. These variables include building orientation, plan depth, window-to-wall ratio, shading configuration, and sectional articulation. Orientation scenarios examine cardinal alignments to evaluate solar exposure patterns and daylight distribution. Plan depth variations assess the relationship between floor plate depth and daylight penetration. Window-to-wall ratio is systematically adjusted within ranges commonly applied in public buildings, avoiding extreme values that are impractical in real-world construction. Shading configurations include externally mounted horizontal and vertical devices designed to mitigate direct solar radiation while permitting diffuse daylight entry. Sectional articulation is evaluated through variations in window head height and vertical placement. Each variable is examined through controlled simulation scenarios in which all other parameters are held constant. This parametric approach allows isolation of individual effects while enabling comparative analysis across configurations.

➢ *Performance Metrics and Evaluation Criteria*

Daylighting performance is evaluated using climate-based daylight metrics that reflect both availability and usability of daylight within occupied spaces. Daylight autonomy is employed to indicate the proportion of occupied hours meeting target illuminance levels, while supplementary metrics are used to identify potential glare risk and over-illumination conditions (Mardaljevic et al., 2009). Energy performance is assessed through annual lighting energy consumption and cooling energy demand. Rather than treating these metrics independently, the study evaluates their combined effect to determine net operational energy performance. Configurations that reduce lighting energy at the expense of disproportionate increases in cooling demand are considered suboptimal, even if daylight metrics alone appear favorable. Energy maximization is therefore defined as the achievement of useful daylight that meaningfully reduces artificial lighting dependence while maintaining cooling energy demand within acceptable limits for hot tropical public buildings.

➢ *Analytical Procedure*

The analytical procedure follows a sequential process. First, baseline simulations establish reference daylighting and energy performance for the base model. Second, parametric simulations evaluate individual daylighting variables across defined ranges. Third, integrated analysis compares daylight and cooling outcomes to identify configurations that achieve balanced performance. Finally, results are synthesized to extract design-relevant patterns rather than isolated numerical optima. This procedure ensures methodological transparency and supports the derivation of conclusions grounded in both quantitative performance data and architectural interpretation.

IV. RESULTS

➢ *Daylighting Performance across Design Variables*

Figure 1 illustrates spatial daylight autonomy (sDA) distributions for the baseline model and plan-depth variants. The baseline configuration achieved sDA across approximately 25–35% of the regularly occupied floor area, with useful daylight largely confined to perimeter zones within 3–4 m of the façade. Interior zones beyond this depth remained predominantly dependent on artificial lighting during occupied hours.

Shallow plan configurations exhibited markedly improved daylight performance, achieving sDA across 55–70% of occupied floor area, representing an improvement of approximately 25–40 percentage points relative to the baseline. Deep plan configurations showed limited responsiveness to increased glazing, with sDA rarely exceeding 40%**,** indicating that plan geometry constrained daylight penetration regardless of aperture size.

Orientation effects are summarized in Figure 2. North–south–oriented configurations produced more temporally stable daylight conditions, while east–west orientations exhibited higher peak illuminance values concentrated in morning and afternoon periods. In east–west configurations, illuminance exceedance above useful daylight thresholds occurred during approximately 20–30% of occupied hours, indicating elevated glare risk.

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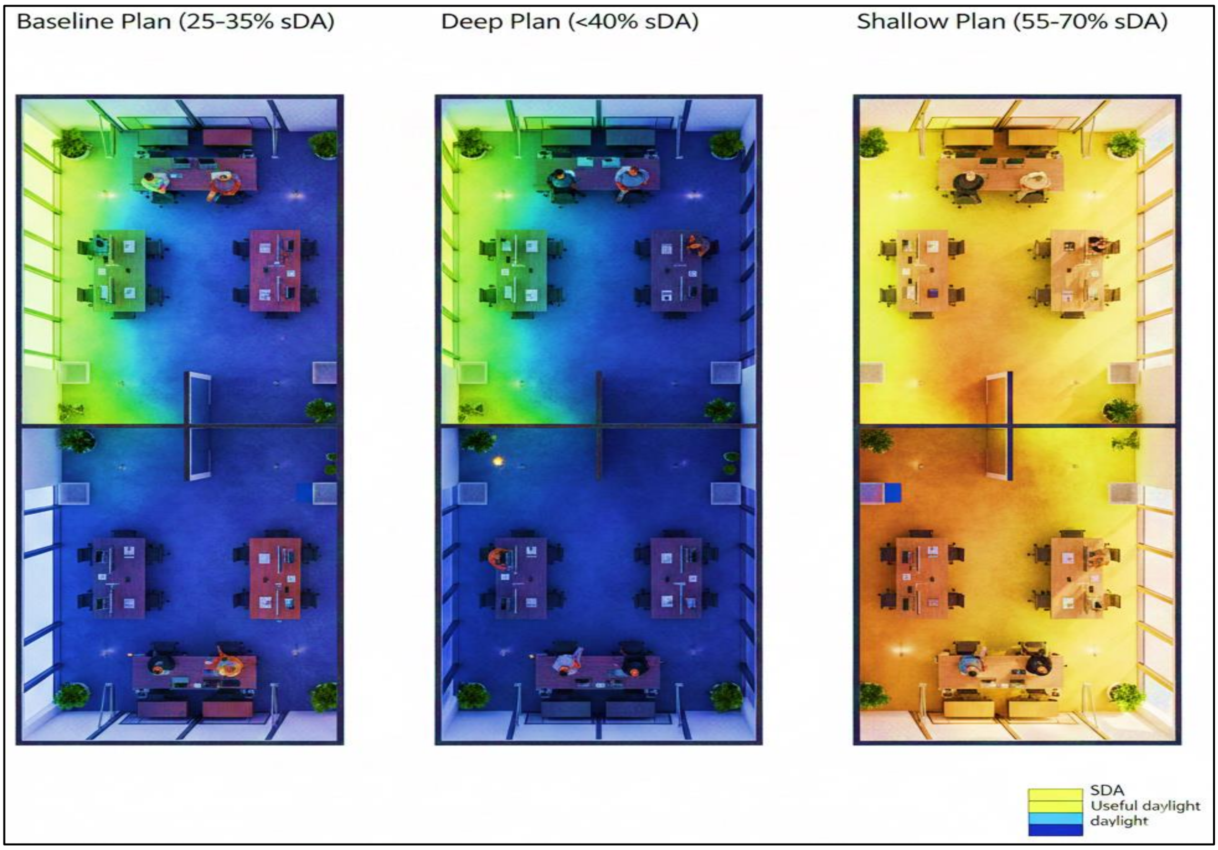

Fig 1 Spatial Daylight Autonomy (sDA) Distributions for the Baseline Model and Plan-Depth Variants.

Table 1: Annual Illuminance Exceedance Time Fraction (%) by Orientation, Obstruction Angle, and Road Width.

Table 1a: East Orientation

Obstruction Angle (°)	**10 m**	**20 m**	**30 m**
0	18.5	20.2	21.8
20	17.9	19.5	21.0
40	15.6	17.2	18.9
60	13.2	14.8	16.1
80–87	11.0	12.6	13.8

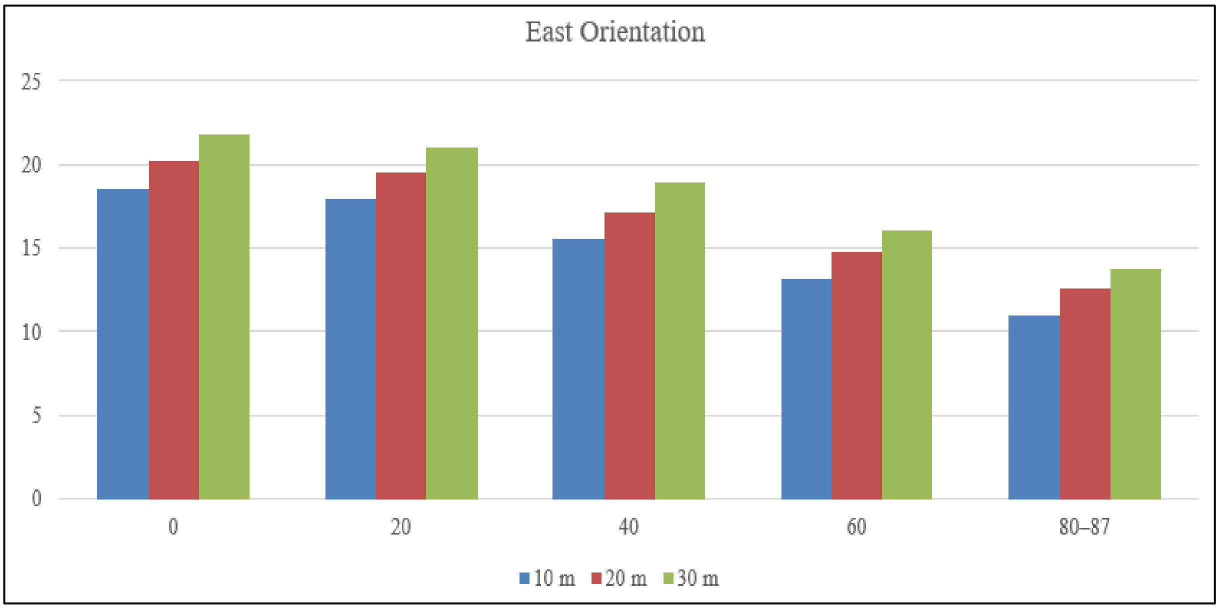

Fig 2 East Orientation

Table 1b: North Orientation

Obstruction Angle (°)	10 m	20 m	30 m
0	14.8	16.5	18.1
20	14.2	15.9	17.4
40	13.6	15.2	16.8
60	13.1	14.7	16.2
80–87	12.8	14.3	15.9

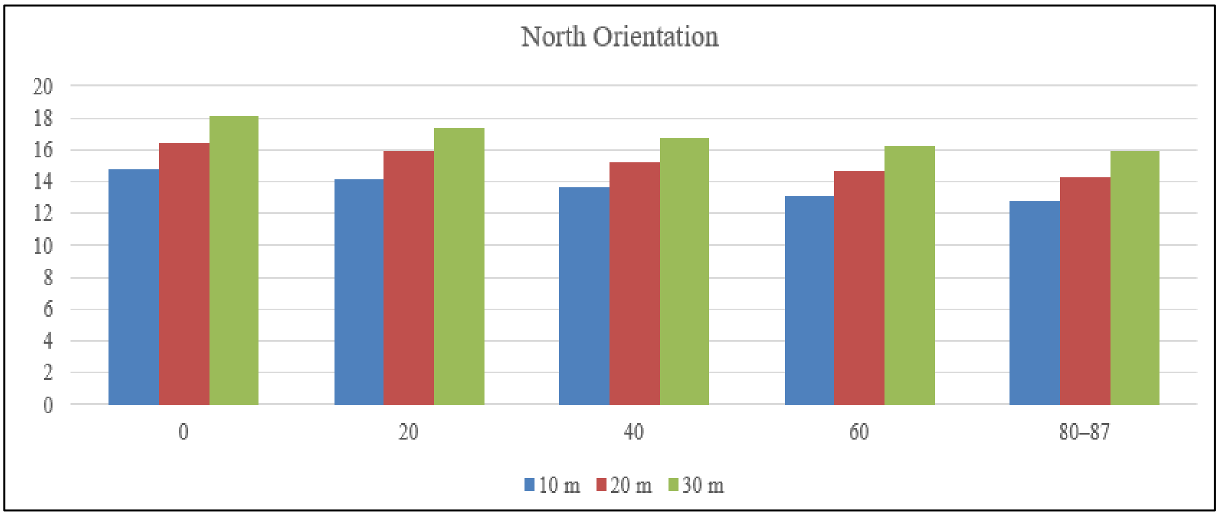

Fig 3 North Orientation

Table 1c: South Orientation

Obstruction Angle (°)	10 m	20 m	30 m
0	16.9	18.4	19.9
20	16.4	17.9	19.2
40	15.8	17.2	18.6
60	13.9	15.4	16.8
80–87	12.5	13.9	15.3

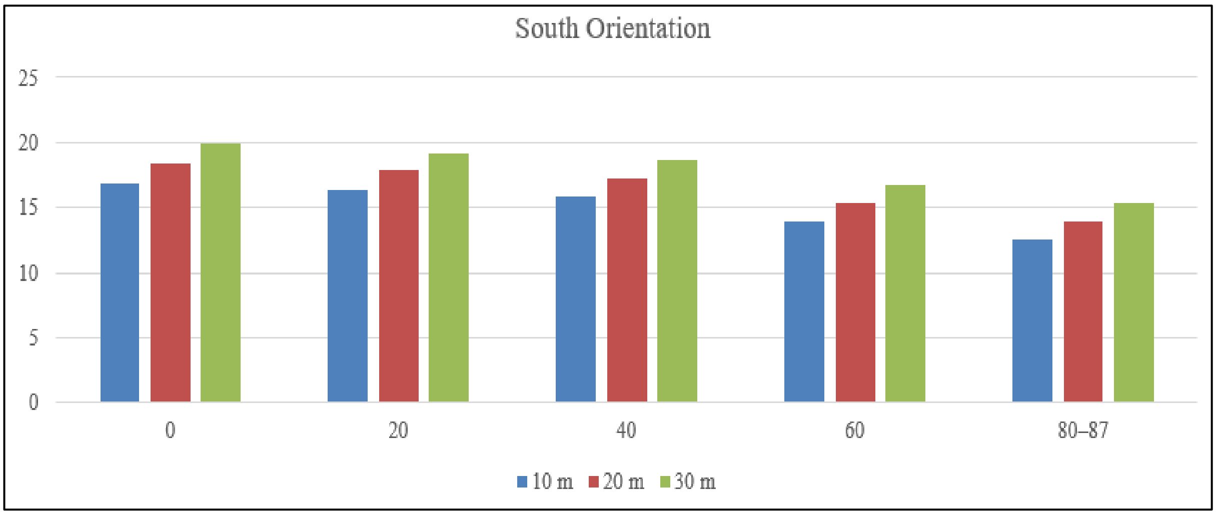

Fig 4 South Orientation

Table 1d: West Orientation

Obstruction Angle (°)	10 m	20 m	30 m
0	17.6	19.1	20.5
20	16.8	18.3	19.8
40	14.7	16.3	17.9
60	12.9	14.5	16.1
80–87	11.3	12.9	14.2

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Fig 5 West Orientation

Table 2 quantifies the relationship between window-to-wall ratio (WWR) and daylight autonomy. Increasing WWR from low to moderate ranges yielded daylight autonomy gains of 15–25 percentage points. Further increases beyond moderate WWR resulted in marginal gains of less than 5–8 percentage points, indicating diminishing daylight returns.

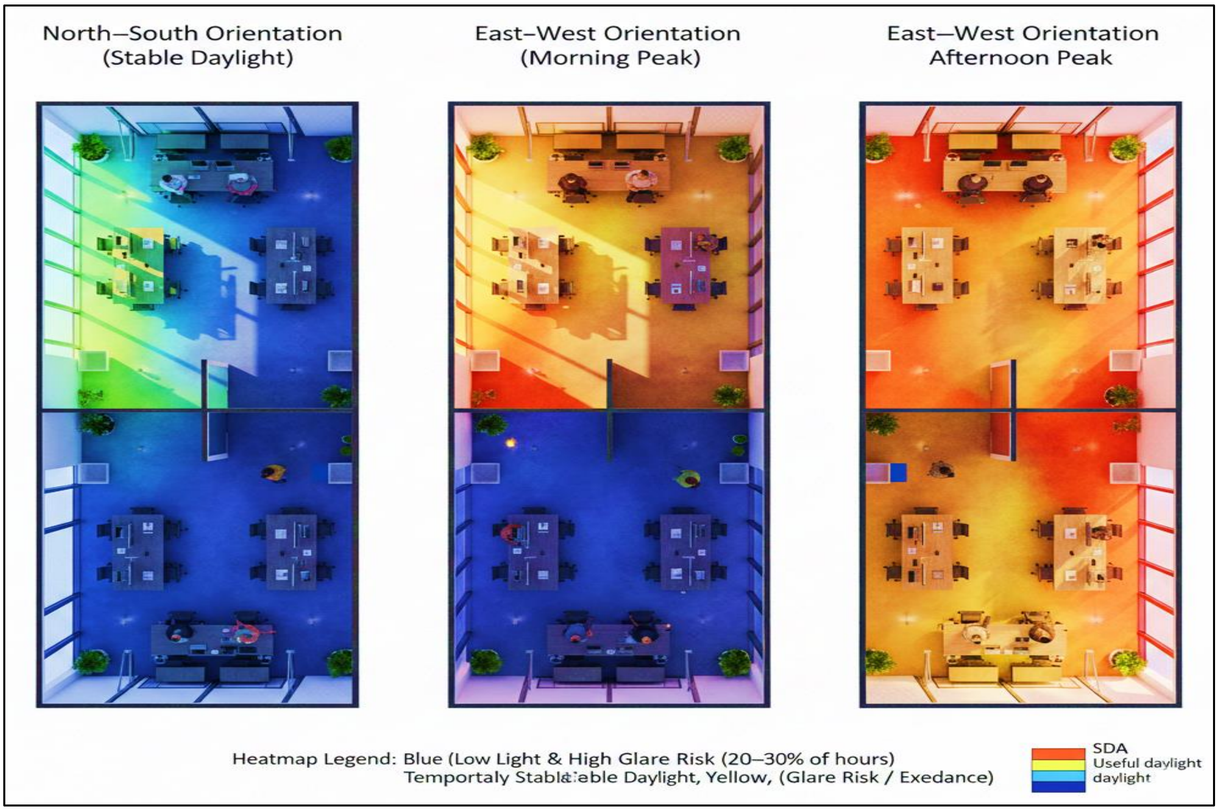

Fig 6 Heatmap Legend: Blue (Low Light & High Glare Risk (20-30% of hours) Temportaly Stabl&:able Daylight, Yellow, (Glare Risk/ Exedance)

Sectional articulation influenced daylight penetration depth rather than aggregate availability. Increasing window head height extended effective daylight penetration by approximately 0.5–1.2 m in shallow and moderate plan depths, contributing to more uniform illuminance distribution (Figure 7).

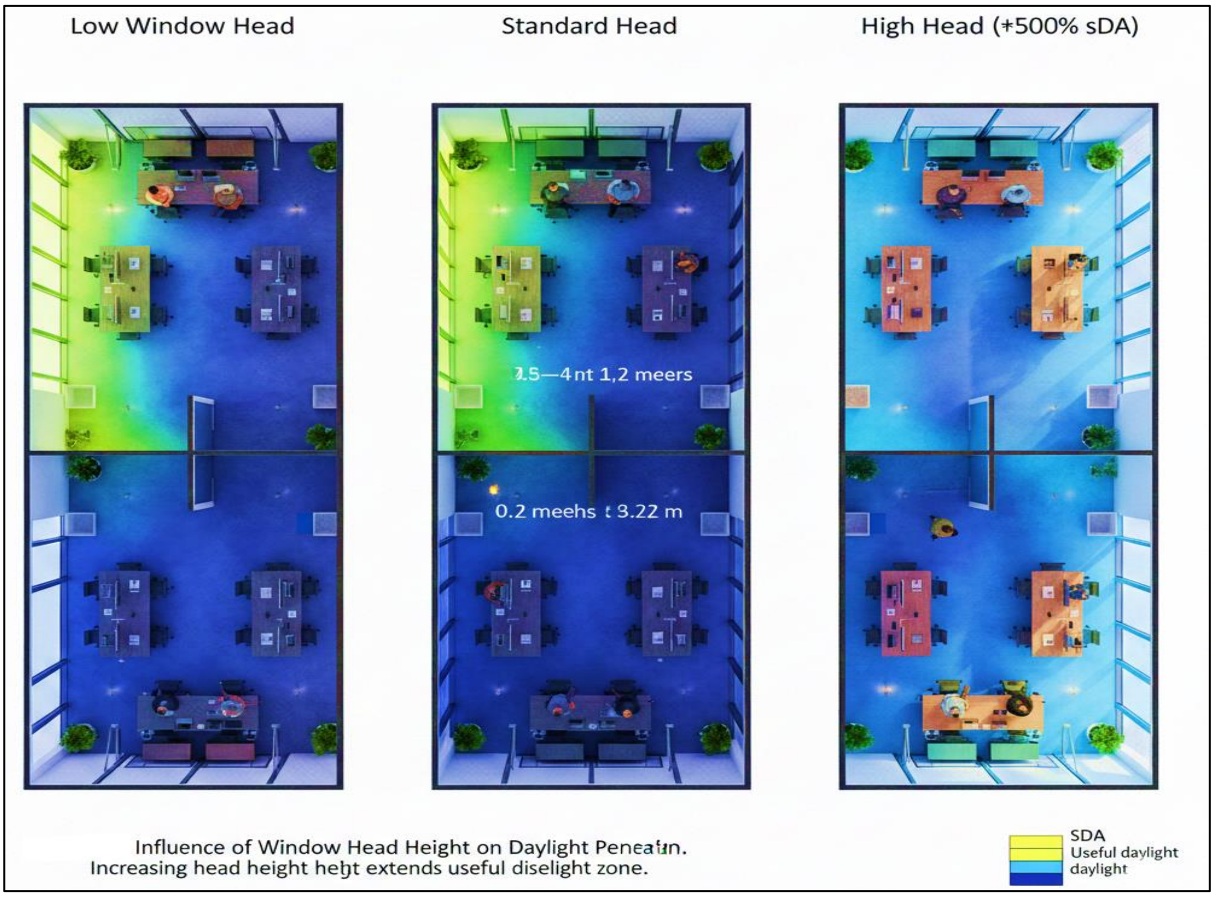

Fig 7 Influence of Window Head Height on Daylight Peneatan. Increasing Head Height Hebt Extends Useful Diselight Zone.

Table 2 Daylighting Performance Ranges by Window-to-Wall Ratio

Window-to-Wall Ratio	Daylight Autonomy (%)	Marginal Gain (%)
Low	25–35	—
Moderate	45–60	+15–25
High	50–65	+5–8

➢ *Cooling Energy Demand by Configuration*

Annual cooling energy demand results relative to the baseline model are summarized in Table 4.2. Configurations with increased glazing exhibited cooling energy increases in the range of 12–30%, depending on orientation and shading condition. The highest cooling penalties were observed in unshaded east–west–oriented scenarios, where low-angle solar radiation coincided with peak occupancy periods.

External shading devices substantially moderated cooling demand. Shaded configurations reduced cooling energy increases by approximately 8–15 percentage points relative to unshaded equivalents. Combined horizontal and vertical shading strategies were particularly effective in east–west orientations. Plan depth influenced cooling demand indirectly. Shallow plans exhibited cooling energy increases of approximately 5–10% relative to deeper configurations due to increased exposed envelope area, though these increases were consistently lower than those driven by excessive glazing. Sectional articulation produced relatively small cooling energy variations. Increased window head height resulted in cooling energy increases of less than 3–5% when unshaded and negligible differences when combined with effective shading.

Table 3 Cooling Energy Demand Changes Relative to Baseline

Configuration Variable	Cooling Energy Change (%)
Increased WWR (Unshaded)	+12 to +30
Increased WWR (Shaded)	+5 to +15
Shallow Plan Depth	+5 to +10
Increased Window Head Height	+3 to +5

➢ *Integrated Lighting and Cooling Energy Performance*

Figure 8 presents the trade-off between annual lighting energy savings and corresponding cooling energy penalties across all simulated configurations. Lighting energy reductions ranged from 20–45% relative to the baseline. Configurations achieving the highest lighting savings

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typically incurred cooling energy increases exceeding 25–30%, resulting in unfavorable net operational energy outcomes. Balanced performance was observed in configurations combining moderate WWR, shallow to moderate plan depths, elevated window head heights, and effective external shading. These configurations achieved lighting energy reductions of 25–35% while limiting cooling energy increases to 5–12%, yielding the most favorable integrated energy profiles. Table 4.4 summarizes the integrated performance bands identified across simulations.

Table 4 Integrated Daylighting–Cooling Performance Bands

Performance Band	Lighting Energy Reduction (%)	Cooling Energy Increase (%)
Poor	30–45	25–35
Moderate	20–30	15–25
Optimal	25–35	5–12

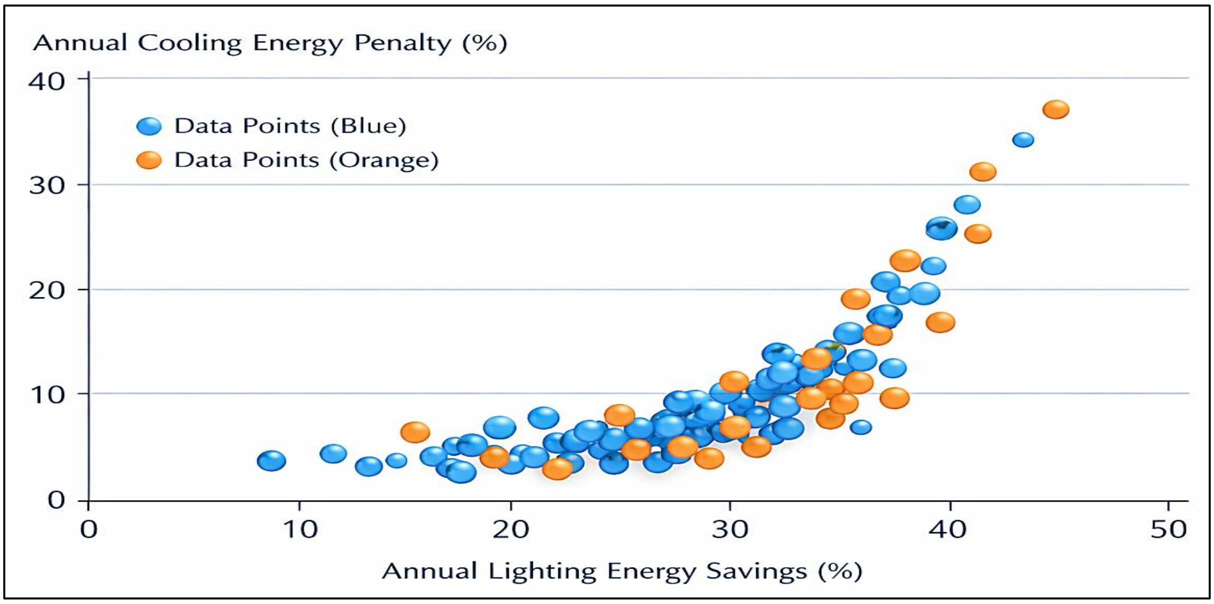

Fig 8 Scatter Plot of Annual Cooling Energy Penalty (%) vs. Annual Lighting Energy Savings (%).

➢ *Quantitative Patterns Summary*

Across all simulations, three dominant quantitative patterns emerged:

- Daylight autonomy increased sharply with reductions in plan depth and moderate increases in glazing but plateaued beyond identifiable thresholds.
- Cooling energy demand scaled approximately with solar exposure, with glazing ratio and orientation exerting stronger influence than plan depth or sectional articulation.
- Optimal integrated performance occurred within a narrow design band where lighting energy reductions of 25–35% were achieved without cooling energy increases exceeding 10–12%.

These results establish that energy-effective daylighting in hot tropical public buildings depends on controlled admission rather than maximum daylight exposure.

V. DISCUSSION

➢ *Reframing Daylighting Effectiveness in Hot Tropical Public Buildings*

The results demonstrate that daylighting effectiveness in hot tropical public buildings cannot be evaluated through daylight availability metrics alone. Configurations that achieved the highest daylight autonomy values frequently imposed cooling energy penalties large enough to negate lighting energy savings. This confirms that, under cooling-dominated climatic conditions, daylighting operates within a constrained performance envelope defined by solar heat gain rather than illumination demand. The finding that optimal integrated performance occurred within a narrow band of lighting energy reduction (25–35%) coupled with limited cooling energy increase (5–12%) is particularly significant. It suggests that energy-effective daylighting in hot tropical contexts is not a maximization problem but a calibration problem. Designs that pursue high daylight metrics as an end in themselves systematically overshoot thermal thresholds, resulting in higher total operational energy use despite apparent daylighting success. This reframing challenges persistent assumptions in daylighting discourse that equate higher daylight autonomy with better energy performance. In hot tropical public buildings, such an assumption is not merely inaccurate but counterproductive.

➢ *Role of Plan Depth as a Primary Daylighting Constraint*

Among the variables examined, plan depth emerged as the most structurally determinative factor for daylight performance. Shallow plans consistently enabled higher daylight autonomy across a greater proportion of floor area without requiring excessive glazing. In contrast, deep plans exhibited persistent daylight deficits regardless of increases

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in window-to-wall ratio or aperture height. This outcome underscores that geometric configuration precedes envelope optimization in determining daylight effectiveness. Attempts to compensate for deep plans through increased glazing produced diminishing daylight returns while exacerbating cooling demand. From an architectural standpoint, this indicates that daylighting strategies applied late in the design process, after plan geometry has been fixed, are inherently limited in their capacity to improve energy performance in hot tropical public buildings. The implication is clear: plan depth should be treated as a first-order environmental design variable rather than a secondary spatial consideration.

- *Glazing, Shading, and the Limits of Aperture-Based Optimization*

The nonlinear relationship between window-to-wall ratio and daylight performance observed in the results reinforces existing evidence that excessive glazing yields diminishing daylight benefits while imposing disproportionate thermal penalties. Moderate glazing ranges consistently outperformed high-glazing configurations in integrated energy terms, particularly when paired with effective external shading. External shading emerged not as a supplementary enhancement but as a prerequisite for viable daylighting in hot tropical climates. Shaded configurations demonstrated substantially reduced cooling penalties while preserving a significant portion of daylight availability. Without shading, even modest increases in glazing produced energy outcomes that were difficult to justify from an operational perspective. These findings position shading devices as integral components of the daylighting system rather than add-ons. In public buildings, where façade articulation often prioritizes representational concerns, this evidence argues for a revaluation of shading as a core performance-driven architectural element.

- *Orientation Sensitivity and Design Risk*

Orientation-related performance differences reveal an important dimension of design risk. North–south–oriented configurations exhibited greater tolerance for daylight admission before incurring excessive cooling penalties, while east–west–oriented configurations demonstrated narrow performance margins and heightened sensitivity to solar control failures. The elevated cooling penalties and illuminance exceedance associated with east–west orientations indicate that daylighting strategies in such configurations are inherently less forgiving. Achieving acceptable integrated performance required more aggressive and precisely tuned shading strategies. This suggests that orientation decisions in hot tropical public buildings carry long-term operational consequences that cannot be fully mitigated through envelope optimization alone. From a design governance perspective, this reinforces the need for orientation-aware planning guidelines rather than uniform daylighting prescriptions.

- *Sectional Articulation as a Secondary but Strategic Variable*

Sectional articulation, particularly increased window head height, contributed meaningfully to daylight penetration depth and spatial uniformity without imposing substantial cooling penalties when combined with appropriate shading. While its impact was secondary relative to plan depth and glazing ratio, sectional design offered a low-risk mechanism for improving daylight distribution in shallow and moderate plans. This finding stresses the importance of vertical design decisions in daylighting performance, an aspect often underemphasized in plan-centric analyses. In public buildings with constrained footprints, sectional strategies may offer one of the few viable pathways for enhancing daylight performance without escalating thermal loads.

- *Implications for Passive Design Integration*

Taken together, the results affirm that daylighting effectiveness in hot tropical public buildings is contingent on its integration within a broader passive design framework. Daylighting strategies that are conceived independently of thermal performance, spatial configuration, and orientation are unlikely to deliver net energy benefits. The evidence supports a design logic in which daylighting is subordinated to thermal control rather than treated as an autonomous objective. Within this logic, useful daylight becomes a byproduct of climate-responsive form-making rather than a metric-driven target. This integrated perspective is particularly relevant for public buildings in cities such as Makurdi, where long-term operational costs and energy resilience are critical public concerns. The findings suggest that modest, well-controlled daylighting strategies embedded within climate-sensitive architectural form can outperform more aggressive daylighting interventions that disregard cooling implications.

VI. CONCLUSION

This study set out to evaluate daylighting as a passive strategy for energy maximization in public buildings within a hot tropical climate, using Makurdi as a representative urban context. The results demonstrate unambiguously that daylighting effectiveness in such environments is not a matter of increasing daylight availability but of regulating solar exposure within strict thermal limits. Across all configurations tested, daylighting strategies that pursued high daylight autonomy through increased glazing or solar admission consistently incurred cooling energy penalties large enough to undermine net operational performance. Conversely, configurations that constrained solar gains too aggressively reduced cooling demand but failed to deliver meaningful reductions in lighting energy. Optimal performance was achieved only within a narrow design band, where controlled daylight admission produced moderate lighting energy reductions without triggering disproportionate increases in cooling demand. Three conclusions follow directly from this evidence. First, plan depth is the dominant determinant of daylighting effectiveness in hot tropical public buildings. Shallow and moderately deep plans enable useful daylight penetration with significantly lower thermal risk than deep-plan alternatives, regardless of envelope refinement. Second, window-to-wall ratio exhibits clear diminishing returns in daylight performance beyond moderate thresholds, while its thermal penalties continue to increase. Excessive glazing is therefore energetically unjustifiable in cooling-dominated

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climates. Third, external shading is not optional. It is a necessary condition for any daylighting strategy that aims to reduce lighting energy without increasing total operational energy use.

Orientation and sectional articulation further condition daylighting outcomes by shaping the margin for error within which daylight strategies can operate. North–south orientations allow greater tolerance for daylight admission, while east–west orientations demand stringent solar control to avoid performance failure. Sectional strategies, particularly elevated window head heights, offer secondary but valuable means of improving daylight distribution when integrated with appropriate shading. Taken together, these findings argue for a fundamental recalibration of daylighting practice in hot tropical public buildings. Daylighting should not be treated as an isolated environmental feature or a visual comfort exercise, but as a subordinate component of a climate-responsive passive design system governed primarily by thermal logic. In this context, useful daylight emerges as a carefully managed resource rather than a maximized target. This study, in providing climate-specific, integrative evidence from a hot tropical urban setting such as Makurdi, contributes to the growing body of work calling for performance-driven architectural decision-making in cooling-dominated climates. The implications extend beyond the case study itself, offering design-relevant guidance for public buildings across similar tropical contexts where energy efficiency, operational cost control, and environmental resilience are increasingly urgent concerns.

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