

Optimization of Building Forms and Orientation in Influencing Daylighting Distribution and Energy Use in Academic Buildings

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Abstract

Daylighting is a critical determinant of visual comfort, energy efficiency, and learning outcomes in architecture schools, where prolonged studio-based visual tasks demand high-quality natural illumination. In tropical regions such as Karu, Nigeria, daylight is abundant, yet its intensity must be carefully controlled to avoid glare and overheating. This study assessed the effects of building forms and architectural elements on daylight optimization in academic buildings. A case study research design supported by a mixed-method approach was adopted, involving field observation, photographic documentation, and on-site lux-meter measurement of three Faculty of Architecture buildings within comparable tropical climatic regions of Nigeria. alongside a structured questionnaire administered to 45 architecture-related students (40 validated responses). Daylight performance was evaluated using Outdoor Illuminance, Average Indoor Illuminance, Daylight Factor (DF), and the Daylight Uniformity Ratio. Findings revealed average indoor illuminance of 1,300, 1,800, and 1,167 lux, and Daylight Factors of 2.1%, 2.8%, and 2.1% respectively, with the courtyard-based University of Lagos building achieving the most balanced glare control despite comparatively lower illuminance. None of the case studies incorporated clerestories, skylights, or light shelves. Users demonstrated strong knowledge of conventional daylighting strategies, but financial, technical, and institutional barriers were found to inhibit their integration into the built form. The study concludes that daylight optimization is best achieved through the deliberate, early, and interdisciplinary integration of building form, orientation, window-to-wall ratio, shading, and interior reflectance, and recommends specific design targets for the achieving daylighting distribution and energy consumption in the design and construction of future academic buildings in the long run.

1.0 Introduction

Natural light has evolved from a passive environmental condition to a critical design parameter that directly influences spatial quality, energy performance, and user well-being (Piraei, Matusiak and Lo Verso 2022). In Architecture academic buildings, daylight is not merely a source of illumination but an essential component of studio-based learning, which requires prolonged visual engagement in drawing, model-making, and digital visualisation, demanding adequate illumination, uniform distribution, minimal glare, and appropriate contrast (Kaushik, Arif, Tumula and Ebohon 2020). Poor daylighting conditions can lead to visual fatigue, reduced productivity, and diminished cognitive performance (Ticleanu, 2021, Baloch et al., 2021). The effectiveness of daylighting is largely determined by building form and architectural elements. Building form, encompassing geometry, massing, orientation, height, and spatial configuration, governs how

sunlight interacts with a structure (Watson, 2020; Lechner, 2021), while elements such as windows, skylights, light shelves, shading devices, and façade treatments regulate the quality and distribution of admitted light. In tropical regions such as Karu, daylight is abundant year-round due to high solar angles and consistent day lengths; however, this abundance presents a paradox, as controlling intensity and thermal impact becomes a significant design challenge (Boubekri, 2021). Optimisation in such climates therefore requires a delicate balance between maximising illumination and minimising heat gain (Lechner, 2021).

Academic institutions with ongoing infrastructural development, provides a relevant context for examining these dynamics of building forms and elements in enhancing daylighting distribution and energy consumption particularly within the Faculty of Architecture, which demands a high level of environmental responsiveness due to its unique pedagogical needs. Despite advancements in architectural knowledge, many institutional buildings in Nigeria continue to exhibit limited integration of climate-responsive design, with building forms often dictated by aesthetic preference or spatial constraint rather than environmental performance (Oladokun & Adebamowo, 2021), resulting in spaces that are either underlit or overexposed and an increased reliance on artificial lighting and mechanical cooling (Oyedepo, 2020).

It is against this gap in knowledge that this studies aim is to assess the effects of building forms and elements on daylight optimization in the design of academic buildings with special emphasis on the faculty of Architecture with a view to enhancing daylight optimization and user comfort within these building types. The specific objectives are to: (i) identify the building forms and elements that enhance daylight optimization in educational buildings; (ii) examine the extent to which these forms and elements have been integrated in such building typologies; (iii) examine the barriers that inhibit their integration; (iv) identify the factors that influence optimal daylight performance.

2.0 Methodology

This study adopted a case study research design supported by a mixed-method approach, integrating qualitative and quantitative techniques to comprehensively assess the effects of building forms and architectural elements on daylight optimisation. The qualitative component involved visual assessment, spatial analysis, and descriptive evaluation of plan configuration, building massing, façade composition, orientation, window design, shading strategies, and glazing techniques. The quantitative component involved measurement of Outdoor Illuminance (E_{out}), Average Indoor Illuminance (E_{in}), Daylight Factor (DF), and the Daylight Uniformity Ratio (U), the only performance indicators measurable directly with a lux meter given that the study's scope excluded daylight simulation software. A total of 45 questionnaires were also administered randomly to respondents within the case study academic buildings with 40 valid responses retrieved. Primary data were collected through field observation using a structured observational checklist covering general information, building form, daylighting elements, daylight performance measurements, and visual comfort assessment; daylight measurement using a calibrated digital lux meter, with nine readings taken across each design studio at working plane height (0.75–0.85 m); and photographic documentation. Secondary data were obtained from architectural drawings and relevant lighting standards, including IES (2020), CIBSE (2019), and BS EN 17037 (2021). A structured questionnaire, comprising sections on users' knowledge, perceived integration, barriers, and enabling factors relating to daylight optimization strategies, was administered to selected respondents. Qualitative data were analyzed descriptively to identify patterns of daylight distribution and design characteristics. Quantitative data were analyzed using simple percentage

methods and the following relationships: Average Illuminance (Eavg) was computed as the mean of nine-point readings; the Daylight Factor was computed as $E_{in}/E_{out} \times 100\%$; and the Daylight Uniformity Ratio was computed as E_{min}/E_{avg} . Results were benchmarked against recommended standards for average illuminance (750–1,000 lux for architecture studios), Daylight Factor (3–5% considered good), and Uniformity Ratio (0.6–0.7 considered good to excellent), drawn from IES (2020), CIBSE (2019), and BS EN 17037 (2021).

3.0 Literature Review

3.1 Concept of Daylighting and Daylight Optimisation

Daylighting refers to the controlled admission and distribution of natural light within interior spaces to achieve visual comfort and reduce dependence on artificial lighting (Piraei, Matusiak and Lo Verso 2022). Successful daylighting must meet three fundamental criteria: adequate illumination for task performance, uniform distribution to avoid contrast and shadowing, and effective glare control (Illuminating Engineering Society, 2020). Daylight optimization extends this concept into a performance-driven approach that balances illumination levels, glare control, and thermal comfort through building form, orientation, and façade treatment (Tregenza and Mardaljevic 2018) ensuring daylight is evenly distributed, sufficient for visual tasks, and contributes to energy efficiency.

3.2 Building Form and Daylight Performance

Building form is a fundamental determinant of daylight performance, establishing the framework within which daylight operates (Tregenza and Mardaljevic 2018); even well-designed façade systems cannot compensate for poor building form. Plan depth is a critical parameter, as daylight penetration typically extends only 6–9 metres from a window under standard conditions, beyond which illuminance levels drop significantly (Piraei, Matusiak and Lo Verso 2022). Linear and shallow-plan configurations maximize façade exposure and daylight penetration, whereas compact or centralized forms restrict daylight access, resulting in poorly illuminated core spaces. Courtyard and atrium configurations address this limitation by introducing additional vertical surfaces and internal light wells through which daylight can enter from multiple directions (Piraei et al 2022).

3.3 Daylight Performance Metrics

Daylight performance is conventionally assessed using the Daylight Factor (DF), the ratio of indoor to simultaneous outdoor illuminance expressed as a percentage under standardized sky conditions (IES, 2012), interpreted using thresholds ranging from inadequate (<2%) to excellent (>5%). More dynamic, climate-based metrics such as Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (sDA), and Annual Sunlight Exposure (ASE) provide a more comprehensive assessment of daylight availability, usability, and potential glare over the course of a year (Shafavi, Tahsildoost and Zomorodian 2020), though their application typically requires dedicated simulation software such as Radiance, DIALux, or Climate Studio.

4.0 Results

4.1 Comparative Case Study Findings

Table 1 summarizes the building form, architectural elements, and daylight performance results recorded across the three case studies. The Faculty of Architecture, University of Jos, exhibited a linear building form on a North–South orientation, a moderate plan depth of 10.5 m, and an estimated window-to-wall ratio of 15–18%, supported by fins, overhangs, and reflective interior

finishes. Measurement produced an average indoor illuminance of 1,300 lux against an outdoor illuminance of 60,000 lux, yielding a Daylight Factor of 2.1% and a Uniformity Ratio of 0.70, rated ideal in daylight distribution with moderate glare.

Table 1: Comparative summary of building form, elements, and daylight performance across the three case studies

Parameter	UNIJOS	FUT Minna	UNILAG	Recommended Standard
Building Form	Linear	Linear	Courtyard/U-Shape	—
Orientation	N–S	N–S	Varies	N–S preferred
Plan Depth (m)	10.5	12.0	10–12	6–9 (ideal)
Floor–Ceiling Height (m)	3.6	3.8	3.5	> 3.5
Est. WWR (%)	15–18	32	Moderate–High	25–35
Outdoor Illuminance (lux)	60,000	65,000	55,000	—
Avg. Indoor Illuminance (lux)	1,300	1,800	1,167	750–1,000
Daylight Factor (%)	2.1	2.8	2.1	3–5 (good)
Uniformity Ratio	0.70	0.72	0.60	0.6–0.7
Glare Occurrence	Moderate	High	Moderate	Low preferred
Daylight Distribution	Ideal	Excellent	Good	—

Comparative summary of building form, elements, and daylight performance across the three case studies (Source: Researcher's Field Survey, 2026).

The School of Architecture, Federal University of Technology, Minna, similarly adopted a linear form on a North–South orientation but with a greater plan depth (12.0 m), a taller floor-to-ceiling height (3.8 m), and a considerably higher estimated WWR of approximately 32%. This configuration produced the strongest illuminance performance of the three case studies, with an average indoor illuminance of 1,800 lux, a Daylight Factor of 2.8%, and a Uniformity Ratio of 0.72; however, this was accompanied by high glare occurrence and observable solar heat gain, attributable to the absence of adequate external shading relative to the extent of glazing provided. The Faculty of Architecture, University of Lagos, adopted a courtyard/U-shaped building form with varied orientation, a plan depth of 10–12 m, and a floor-to-ceiling height of 3.5 m, supported by deep vertical fins, horizontal overhangs, louvres, and screens. The studio recorded a lower average indoor illuminance of 1,167 lux (against a comparatively lower outdoor illuminance of

55,000 lux), a Daylight Factor of 2.1%, and a Uniformity Ratio of 0.60, rated good, with moderate rather than high glare occurrence, reflecting the moderating effect of the courtyard form and deep shading fins on direct solar penetration.

None of the three case studies incorporated clerestory windows, skylights, light shelves, or light wells, indicating a general reliance on conventional side-lit strategies across Nigerian Faculty of Architecture buildings, and a corresponding gap in the deployment of daylighting devices capable of improving penetration into deeper zones of the studio floor plate. Collectively, the case studies demonstrate that building form alone does not determine daylight performance; rather, daylight optimisation arises from the interaction between building form and architectural elements, including window size and placement, WWR, shading devices, courtyard configuration, ceiling height, and interior surface reflectance.

4.2 Observed Building Forms and Elements in Case Study Buildings

4.2.1 Faculty of Architecture University of Jos



Figure 1: Building Form, Faculty of Architecture University of Jos

4.2.2 School of Architecture, Federal University of Technology Minna (FUT Minna)



Figure 2: Building Form, School of Architecture, Federal University of Technology Minna

4.2.3 Faculty of Architecture, University of Lagos (UNILAG)



Figure 3: Building Form, Faculty of Architecture, University of Lagos

4.3 Survey Findings on User Knowledge, Integration, Barriers, and Enabling Factors

The survey of 40 valid respondents, drawn from the University of Jos (45%), FUT Minna (30%), and UNILAG (25%), and predominantly composed of Architecture students (50%) in their final years of study, revealed generally high user knowledge of conventional passive daylighting strategies. North–South orientation was recognised at high or very high levels by 72.5% of respondents, courtyard design by 80%, and clerestory/high-side windows by 87.5%, while awareness of advanced technologies such as split-level or sawtooth roof forms, fibre-optic daylight systems, and smart or responsive façades remained comparatively low, with 70% of respondents indicating no or very low knowledge of split-level roof forms specifically. With respect to perceived integration, respondents agreed that North–South orientation, courtyard or atrium forms, external shading devices, and reflective interior surfaces had been reasonably well integrated in their respective buildings, whereas clerestory windows, light shelves, light tubes, solar chimneys, and smart façades were perceived to be poorly integrated or their presence was uncertain — corroborating the observational finding that these advanced elements were largely absent from the case study buildings. Regarding barriers, higher initial capital cost recorded the strongest agreement (77.5% agree or strongly agree), alongside long payback periods, perceived maintenance burden, overshadowing from adjacent structures, glare and thermal discomfort, and the shortage of specialised local expertise. Institutional barriers, including administrative risk aversion and the absence of post-occupancy evaluation, were also rated significant, while user interface issues were not considered a major obstacle. In terms of enabling factors, respondents placed strong emphasis on multidisciplinary collaboration, performance-based design briefs, iterative daylight simulation during design, life-cycle cost analysis, access to green building incentives, matching of glazing to orientation, and the use of climate-responsive forms and durable, low-maintenance materials.

Table 2 Summary of the highest- and lowest-rated items across the four survey dimensions.

Survey Dimension	Highest-Rated Item	% Agreement	Lowest-Rated Item
Knowledge of Strategies	Clerestory/high-side windows	87.5%	Split-level/sawtooth roofs
Perceived Integration	External shading devices	60% (SA)	Clerestory windows
Barriers to Integration	Higher initial capital cost	77.5%	User interface
Enabling Factors	Multidisciplinary workshops	87.5%	Campus guideline exceptions

Summary of highest- and lowest-rated survey items across knowledge, integration, barriers, and enabling factors (Source: Researcher's Field Survey, 2026).

A comparison of the knowledge and integration results reveals a consistent pattern: strategies that are structurally embedded in building form at the earliest design stage, such as North–South orientation and courtyard configuration, are both well known and perceived to be well integrated, whereas discrete architectural elements added to the envelope — clerestories, light shelves, and light tubes — are well known but poorly integrated. This pattern reinforces the conclusion that the constraint on daylight optimisation is not a knowledge deficit among future practitioners but a translation gap between design intention and built outcome, driven primarily by the financial and institutional barriers.

5.0 Discussion

The findings demonstrate a clear trade-off between illuminance quantity and visual comfort across the three case studies. Where glazing area was substantially increased without a commensurate increase in external shading, as observed at FUT Minna, daylight illuminance and Daylight Factor improved but at the cost of increased glare occurrence and solar heat gain. Conversely, the courtyard-based configuration at UNILAG, supported by deep shading fins, achieved a more moderate but well-controlled daylight profile, illustrating that courtyard forms combined with robust shading can deliver a more balanced daylight and thermal comfort outcome in tropical climates than reliance on glazing area alone. The linear, moderately deep, North–South oriented form at UNIJOS achieved the most favourable balance of illuminance adequacy (1,300 lux, close to the studio-preferred range) and comfort (ideal distribution, moderate glare), suggesting that moderate plan depth combined with balanced WWR and shading is a particularly effective strategy in this climatic context. The consistent absence of clerestory windows, skylights, light shelves, and light wells across all three case studies, despite users' comparatively strong awareness of these elements, indicates that the barrier to daylight optimisation in Nigerian Faculty of Architecture buildings lies less in a lack of knowledge and more in the financial, technical, and institutional constraints identified by respondents — particularly high initial capital cost, limited specialised local expertise, and the absence of post-occupancy evaluation processes that would otherwise generate a feedback loop for continuous improvement in daylighting design.

The measured Daylight Factor values across all three case studies (2.1%, 2.8%, and 2.1%) fall below the 3–5% range considered good under the recommended standards adopted for this study, despite average indoor illuminance levels approaching or exceeding the preferred range for

architecture studios at two of the three sites. This apparent discrepancy is explained by the exceptionally high outdoor illuminance levels typical of the tropical sky conditions recorded at all three locations (55,000–65,000 lux), which depress the calculated DF ratio even where absolute indoor illuminance is functionally adequate. The differential glare outcomes across the three case studies further highlight the primacy of shading design over glazing area in tropical daylight optimisation. FUT Minna, with the highest WWR (approximately 32%) and the highest illuminance and DF values, also recorded the highest glare occurrence among the three case studies, confirming that increased glazing area without a commensurate increase in external shading provision directly elevates glare risk. By contrast, UNILAG, despite a comparatively lower measured illuminance, achieved only moderate glare through the combination of a courtyard form and deep vertical shading fins, illustrating that glare control in tropical Faculty of Architecture buildings is governed less by the quantity of daylight admitted than by the extent to which admitted daylight is diffused, redirected, or moderated prior to reaching the occupied plane.

6.0 Conclusions and Recommendations

This study assessed the effects of building forms and architectural elements on daylight optimisation in Faculty of Architecture buildings within tropical climatic conditions with a view to informing the design of the University's proposed Faculty of Architecture. The findings confirm that building forms and architectural elements exert a significant and interdependent influence on daylight performance: linear forms with moderate plan depth and balanced window-to-wall ratios can achieve ideal daylight distribution with limited glare when adequately shaded; substantially increased glazing without commensurate shading enhances illuminance at the cost of glare and heat gain; and courtyard-based forms with deep shading fins offer a balanced approach to daylight and thermal comfort. None of the reviewed case studies incorporated advanced daylighting elements such as clerestories, skylights, or light shelves, representing both a persistent gap in current Nigerian practice. While users possess considerable knowledge of conventional passive daylighting strategies, this knowledge has not translated into built form, primarily due to financial, technical, and institutional barriers rather than a lack of awareness. On the basis of these findings, the following recommendations are proposed for academic buildings that intend to optimise daylighting and energy consumption.

- i. Adopt a predominantly linear or courtyard-based building form, aligned North–South or along an elongated East–West axis as appropriate, with a plan depth not exceeding approximately 12 metres.
- ii. Incorporate a courtyard or partial courtyard configuration into design studio blocks to introduce daylight from multiple façades and improve uniformity in deeper zones of the floor plate.
- iii. Calibrate window-to-wall ratios within approximately 25–35%, always paired with appropriate external shading devices such as overhangs, vertical fins, or louvres.
- iv. Incorporate clerestory windows, skylights, light shelves, and light wells, all of which were absent across the case studies, to improve daylight penetration beyond the limits of side-lighting alone.
- v. Maintain floor-to-ceiling heights above 3.5 metres and specify light-coloured, high-reflectance interior finishes to enhance internal daylight distribution.
- vi. Establish explicit daylight performance targets — Daylight Factor of 3–5% and Uniformity Ratio of 0.6–0.7 — from the conceptual design stage, and test design decisions against these targets throughout development.
- vii. Adopt an interdisciplinary, iterative design process involving architects, engineers, and

environmental consultants from the earliest design stage, supported by a performance-based design brief.

viii. Adopt life-cycle cost analysis and phased implementation strategies to address the financial barriers identified as the most significant obstacle to advanced daylighting integration.

ix. Institutionalize post-occupancy evaluation of the completed Faculty of Architecture building to assess actual daylight performance and inform future institutional building projects.

This study contributes an empirically derived, context-specific assessment of building form and architectural element effects on daylight optimisation academic buildings in tropical Nigeria. Future research should apply dynamic, climate-based daylight simulation tools such as Radiance, Climate Studio, or DIALux to validate and refine these recommendations prior to construction, extend performance assessment beyond design studios to lecture rooms, workshops, and circulation spaces, and examine the cost implications and life-cycle performance of daylight-responsive design strategies within the Nigerian construction context.

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