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INTEGRATION OF DYNAMIC SHADING SYSTEMS TO OPTIMIZE DAYLIGHTING AND REDUCE COOLING LOADS IN HIGH-RISE OFFICES

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ABSTRACT

Adequate thermal and visual comfort remains a challenge for many high-rise office buildings in Abuja, Nigeria, where facades often lack proper passive solar shading and rely heavily on mechanical cooling to manage excessive heat gain under the city's hot tropical climate. This study evaluates the use of passive solar shading strategies in high-rise office buildings in Abuja as a means of enhancing user comfort and sustainable design. It examines the status of existing shading knowledge, the extent of current integration, and the technical, economic and regulatory constraints on effective implementation. Using a mixed-methods approach, quantitative data were obtained from 50 architectural and engineering professionals involved in the design of high-rise offices in Abuja, alongside qualitative case-study observation of shading strategies identified from the literature. The results show that of the nine strategies examined, deep reveals and horizontal louvres / light shelves recorded the highest knowledge (Means of 3.74 and 3.48), while integration remained low across every strategy (all means below 3.0). Cost implications and developer priorities were the leading barriers to integration (Means of 4.68 and 4.66), while energy savings and climate responsiveness were rated the highest success factors (Means of 4.96 and 4.70). The study highlights the key focus areas for passive solar shading in high-rise office buildings and recommends directions for embedding the strategy in future design.

Keywords: Passive, Solar, Shading, Sustainable, Design, High-Rise, Comfort, Abuja.

1 INTRODUCTION

Abuja, Nigeria's Federal Capital Territory, is one of the fastest-growing cities in Africa, driven by expanding economic prospects, a rising population and deliberate strategic planning (Ogochukwu et al., 2022). Founded in 1976 as a planned administrative centre to relieve congestion in Lagos, the city's population has surged from around 300,000 in the late 1970s to over four million today, intensifying pressure on the built environment (Ibrahim, 2007). This growth has produced a proliferation of high-rise office buildings serving government, corporate and commercial functions, which now dominate the skyline of the Central Business District, Maitama and Garki.

Abuja's tropical savanna climate (Köppen Aw) raises the energy demands of these buildings through intense solar radiation, high temperatures and seasonal humidity (Mu'azu, 2015). Daily temperatures range from about 15.5 °C at night to 33.8 °C during the day, and solar radiation is especially powerful, averaging 5.5–5.8 kWh/m^2/day and peaking at 5.9–6.3 kWh/m²/day in the clear, low-humidity dry season. This climate produces significant solar heat gains, glare and high cooling demand in buildings that feature extensive glazing, common for aesthetic reasons and views, so that many operate air conditioning around the clock (Lamberti et al., 2024). Table 1 summarises the climatic parameters most relevant to shading design.

Table 1: Climatic characteristics of Abuja relevant to passive solar shading

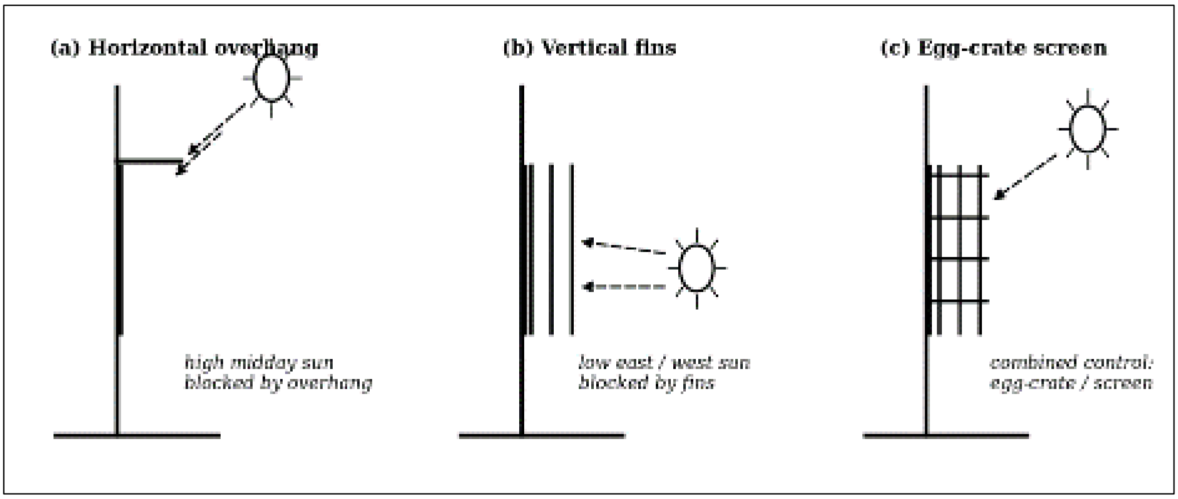
Climatic parameter	Characteristic in Abuja	Implication for shading design
Climate type	Tropical savannah (Köppen Aw)	Year-round solar-control demand
Air temperature	Daily range ≈ 15.5 °C (night) to 33.8 °C (day)	High daytime cooling loads on glazed facades
Solar radiation	≈ 5.5–5.8 kWh/m²/day, peaks 5.9–6.3 in the dry season	Intense gain through unshaded glass; external shading essential
Sun path	Consistently high solar angles year-round	Overhangs for high sun; fins for low east/west sun
Seasons	Wet (May–Oct) and dry / harmattan (Nov–Mar)	Shading must also manage glare and dust
Humidity	≈ 30–40% (dry season) to ≈ 65% (wet season)	Shading paired with ventilation for comfort

Source: compiled by the authors from Mu'azu (2015) and Lamberti et al. (2024).

Passive solar shading is a crucial response to these conditions, using architectural elements to block direct sunlight and reduce heat ingress without mechanical energy (Erebor et al., 2021). In tropical climates such as Abuja's, where solar angles are consistently high, external devices, overhangs, vertical fins, louvres and brise-soleil, are highly effective: vertical fins temper low-angle sun from the east and west, while overhangs block the high-angle midday sun (Dudzińska, 2021). Combined with low solar-heat-gain-coefficient glazing and east–west orientation, such measures can cut cooling requirements by over 30%. The incorporation of passive shading supports Nigeria's sustainable-building agenda, reflected in the National Building Code and the Building Energy Efficiency Code (BEEC) and in the growing adoption of LEED and EDGE certification, yet barriers persist, limited awareness of green technologies, high initial costs and weak enforcement of regulations (Yawas et al.). This study therefore evaluates the use of passive solar shading in Abuja's high-rise offices and asks how it can be optimised to support energy-efficient, comfortable and sustainable design. It pursues four objectives: to identify the shading strategies known to professionals; to examine the extent of their integration; to identify the barriers that inhibit integration; and to investigate the critical success factors that would encourage their continued application.

2 SOLAR SHADING IN ARCHITECTURAL DISCOURSE

Shading the window is one of the oldest problems in architecture, and in the twentieth century it acquired a canonical vocabulary. Le Corbusier's brise-soleil, the “sun-breaker” he developed for projects in North Africa and India and built at scale in the Unité d'Habitation and at Chandigarh and Ahmedabad, established the deep, sculpted, sun-shading facade as a legitimate architectural language for hot climates rather than a mere technical fix. The device works because solar geometry is predictable: the sun is high overhead near midday and low to the horizon in the early morning and late afternoon. As Figure 1 shows, this geometry dictates the form of the shade. A horizontal overhang or louvre blocks the high midday sun on the sun-facing elevation; vertical fins are needed to intercept the low, raking light that strikes the east and west facades; and an egg-crate or perforated screen combines both to give all-round control. Choosing the wrong device for the orientation is a common and costly error, which is why shading is a design decision tied inseparably to orientation.



Source: Authors' construction (2026).

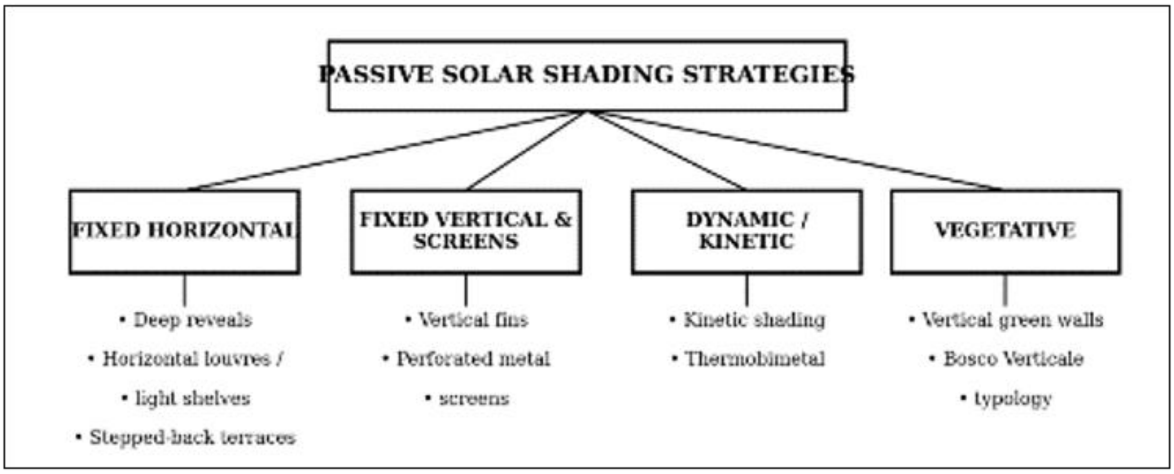
Figure 1: Solar geometry and shading-device type: (a) horizontal overhangs for the high midday sun, (b) vertical fins for the low east/west sun, and (c) egg-crate screens for combined control

The strategies examined in this study extend this vocabulary into contemporary high-rise practice and fall into four families, set out in Table 2 and Figure 2: fixed horizontal devices, fixed vertical devices and screens, dynamic or kinetic systems, and vegetative shading. The families differ sharply in complexity and cost, a deep reveal is essentially free once designed, whereas a kinetic system or a planted "vertical forest" such as Milan's Bosco Verticale demands significant capital and maintenance, a difference that, as the results show, shapes which strategies are actually built.

Table 2: A classification of the passive solar shading strategies assessed

Shading family	Working principle	Strategies assessed in this study
Fixed horizontal	Block high-angle sun above the window	Deep reveals; horizontal louvres / light shelves; stepped-back terraces
Fixed vertical & screens	Block low-angle east/west sun and diffuse glare	Vertical fins; perforated metal screens
Dynamic / kinetic	Adjust to changing sun position and sky conditions	Kinetic shading; thermobimetal
Vegetative	Shade and cool the facade with planting	Vertical green walls on tracks; Bosco Verticale typology

Source: Authors' construction (2026).



Source: Authors' construction (2026).

Figure 2: The four shading families and their representative strategies

3 METHODOLOGY

The study used a mixed-methods approach, combining quantitative survey data with qualitative case-study observation to assess the implementation of passive solar shading in high-rise offices in Abuja's Central Business District. Structured questionnaires were administered to architectural and engineering professionals involved in the design of such buildings, while the qualitative component drew on observation of facades and shading devices and on established international precedents. The questionnaire had five sections matching the objectives, socio-demographics; knowledge of shading strategies; level of integration; barriers; and success factors, each rated on a five-point Likert scale (1 = strongly disagree / no knowledge / not significant to 5 = strongly agree / very high knowledge / very significant).

Because the finite population of professionals was unknown, Cochran's formula (95% confidence, Z = 1.96, 5% margin of error, p = 0.5) was used to establish a target sample of 385. In practice, 50 questionnaires were completed and returned by professionals directly engaged in high-rise office design, and it is this set of 50 expert responses the analysis draws on; the smaller realised sample is a limitation acknowledged in interpreting the results. Data were analysed in SPSS using means, standard deviations and rankings, with the scale mid-point of 3.0 used as the reference for adequacy or agreement.

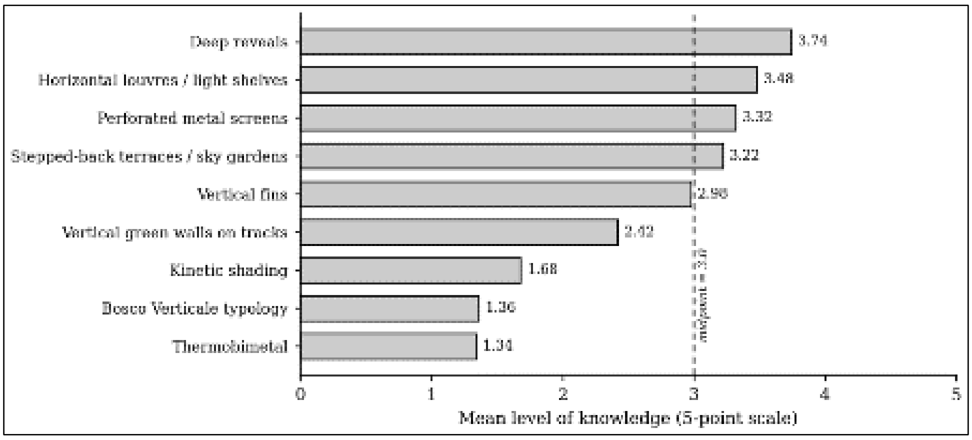
4 RESULTS

4.1 Knowledge of Passive Solar Shading Strategies

Table 3: Knowledge of the passive solar shading strategies (N = 50)

S/N	Passive solar shading strategy	Mean	SD	Rank
1	Deep reveals	**3.74**	0.664	1st
2	Horizontal louvres / light shelves	**3.48**	0.544	2nd
3	Perforated metal screens	**3.32**	0.713	3rd
4	Stepped-back terraces / sky gardens	**3.22**	0.815	4th
5	Vertical fins	**2.98**	0.742	5th
6	Vertical green walls on tracks	**2.42**	0.702	6th
7	Kinetic shading	**1.68**	0.713	7th
8	Bosco Verticale typology	**1.36**	0.525	8th
9	Thermobimetal	**1.34**	0.479	9th

Source: Authors' analysis, SPSS (Field survey, 2025).



Source: Authors' analysis (2025).

Figure 3: Mean level of knowledge of the nine strategies (dashed line = 3.0 mid-point)

Table 3 and Figure 3 report knowledge of the nine strategies. Deep reveals recorded the highest mean (3.74, SD = 0.664), followed by horizontal louvres / light shelves (3.48), perforated metal screens (3.32) and stepped-back terraces / sky gardens (3.22), all simple, fixed, familiar devices. Conversely, thermobimetal (1.34), the Bosco Verticale typology (1.36) and kinetic shading (1.68) scored lowest, indicating that dynamic and landscape-integrated strategies are largely unknown to the professionals surveyed.

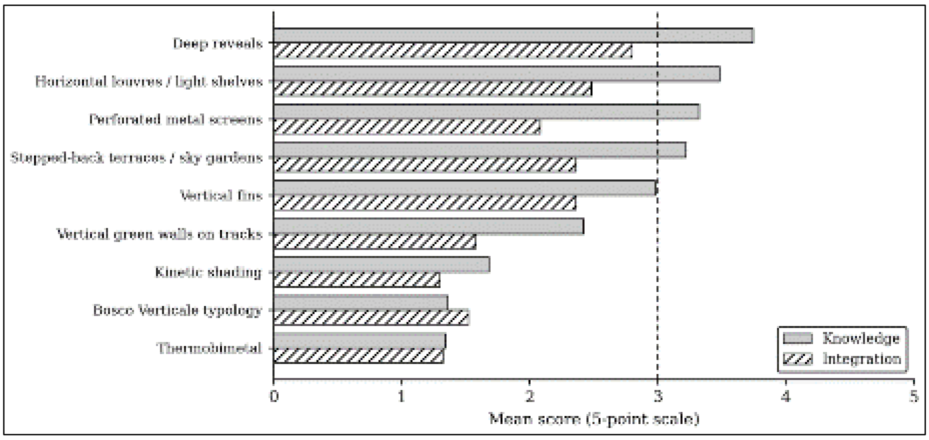
4.2 Current Integration of Passive Solar Shading Strategies

Table 4 reports the perceived level of integration. Deep reveals again ranked highest (Mean = 2.80, SD = 0.756), followed by horizontal louvres / light shelves (2.48) and vertical fins and stepped-back terraces (both 2.36). Critically, every one of the nine strategies scored below the 3.0 mid-point, confirming that integration is inadequate across the board even where knowledge is relatively high. Figure 4 sets knowledge against integration: the gap is large and consistent, professionals know these devices considerably better than they apply them, and even the best-understood, simplest strategy (deep reveals) falls almost a full Likert point from knowledge to practice.

Table 4: Level of integration of the passive solar shading strategies (N = 50)

S/N	Passive solar shading strategy	Mean	SD	Rank
1	Deep reveals	**2.80**	0.756	1st
2	Horizontal louvres / light shelves	**2.48**	0.544	2nd
3	Vertical fins	**2.36**	0.693	3rd
4	Stepped-back terraces / sky gardens	**2.36**	0.749	3rd
5	Perforated metal screens	**2.08**	0.853	5th
6	Vertical green walls on tracks	**1.58**	0.758	6th
7	Bosco Verticale typology	**1.52**	0.886	7th
8	Thermobimetal	**1.32**	0.471	8th
9	Kinetic shading	**1.30**	0.463	9th

Rankings recomputed from the reported means. Source: Authors' analysis, SPSS (2025).



Source: Authors' analysis (2025).

Figure 4: Knowledge (solid) versus integration (hatched); every strategy is applied well below the level at which it is known

4.3 Observed Applications: International Precedents

Because well-integrated examples are scarce among Abuja's high-rise stock, three international precedents were examined to illustrate what thorough shading integration looks like (Table 5). Kingsway Tower in Lagos wraps a curved form in a multi-layered perforated aluminium screen that acts as an advanced brise-soleil, exceptional for its hot-humid adaptation but demanding to maintain. Tokiwabashi Tower in Tokyo uses a blade-like metallic grid referencing Japanese latticework, elegant and resilient but costly. B-One in Berlin combines a self-shading limestone grid with integrated photovoltaics and planted terraces, a world-class sustainability exemplar whose main trade-offs are upfront cost and system complexity. Across all three, successful integration depends on context-specific facade systems, maintenance planning and institutional commitment, the same conditions the survey identifies as barriers and enablers.

Table 5: International precedents illustrating integrated passive solar shading

Precedent (location)	Height / type	Shading strategy	Trade-off noted
Kingsway Tower (Lagos)	15-storey mixed-use	Multi-layered perforated aluminium screen (advanced brise-soleil); deep overhangs	Maintenance burden of complex layered screens
Tokiwabashi Tower (Tokyo)	38-storey mixed-use	Blade-like metallic grid facade referencing Japanese latticework	High cost of advanced systems; facade upkeep
B-One (Berlin)	11-storey headquarters	Self-shading limestone grid, integrated PV and planted terraces	Higher upfront cost; integrated-system complexity

Source: Authors' case-study analysis (2025).

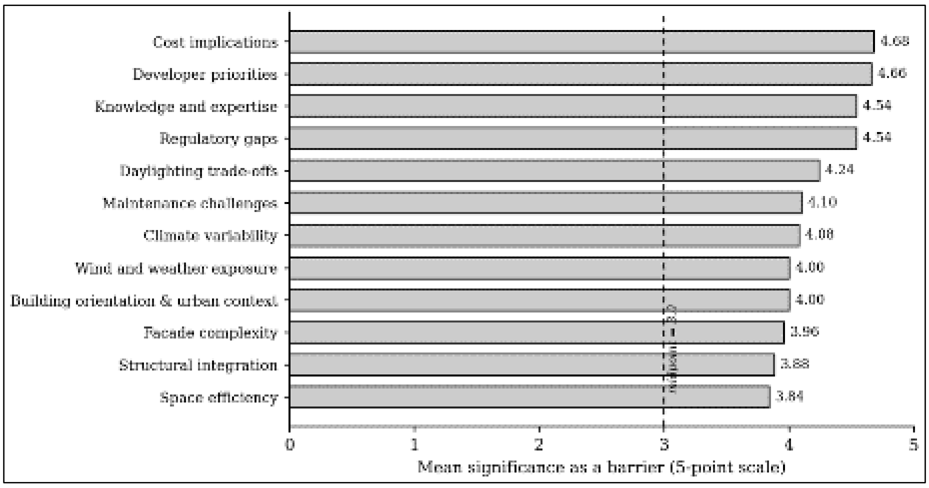
4.4 Barriers to Integration

Table 6 and Figure 5 report the twelve barriers. Cost implications ranked highest (Mean = 4.68, SD = 0.471), followed closely by developer priorities (4.66) and, jointly, regulatory gaps and knowledge and expertise (both 4.54). Even the lowest-ranked barrier, space efficiency (3.84), sits well above the mid-point, indicating that respondents regard the whole set as significant. The dominance of cost and developer priorities gives clear empirical support to the view that short-term commercial returns drive Nigerian real-estate decisions, and that weak code enforcement leaves little counterweight.

Table 6: Barriers that inhibit the integration of passive solar shading strategies (N = 50)

S/N	Barrier	Mean	SD	Rank
1	Cost implications	4.68	0.471	1st
2	Developer priorities	4.66	0.479	2nd
3	Regulatory gaps	4.54	0.503	3rd
4	Knowledge and expertise	4.54	0.503	3rd
5	Daylighting trade-offs	4.24	0.517	5th
6	Maintenance challenges	4.10	0.678	6th
7	Climate variability	4.08	0.665	7th
8	Building orientation & urban context	4.00	0.700	8th
9	Wind and weather exposure	4.00	0.728	8th
10	Facade complexity	3.96	0.755	10th
11	Structural integration	3.88	0.773	11th
12	Space efficiency	3.84	0.842	12th

Rankings recomputed from the reported means. Source: Authors' analysis, SPSS (2025).



Source: Authors' analysis (2025).

Figure 5: Mean significance of the twelve barriers (dashed line = 3.0 mid-point)

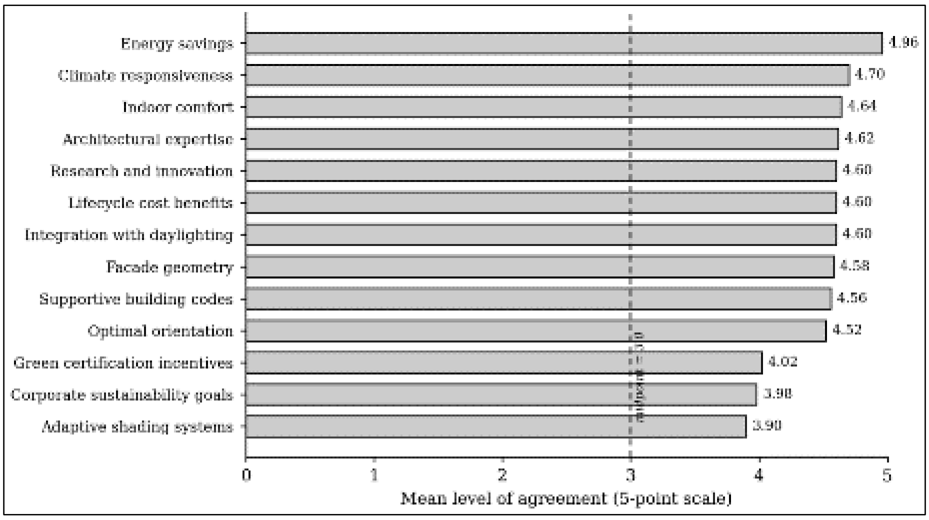
4.5 Success Factors that Enhance Integration

Table 7 and Figure 6 report the thirteen success factors. Energy savings ranked highest by a clear margin (Mean = 4.96, SD = 0.283), followed by climate responsiveness (4.70), indoor comfort (4.64) and architectural expertise (4.62). The prominence of energy savings suggests that framing passive shading in measurable, long-term cost and energy terms is the most compelling route to adoption, a direct answer to the cost and developer-priority barriers that lead Table 6. Table 8 draws the four objectives together.

Table 7: Success factors that enhance the integration of passive solar shading (N = 50)

S/N	Success factor	Mean	SD	Rank
1	Energy savings	4.96	0.283	1st
2	Climate responsiveness	4.70	0.463	2nd
3	Indoor comfort	4.64	0.485	3rd
4	Architectural expertise	4.62	0.490	4th
5	Integration with daylighting	4.60	0.495	5th
6	Lifecycle cost benefits	4.60	0.495	5th
7	Research and innovation	4.60	0.536	5th
8	Facade geometry	4.58	0.499	8th
9	Supportive building codes	4.56	0.541	9th
10	Optimal orientation	4.52	0.580	10th
11	Green certification incentives	4.02	0.820	11th
12	Corporate sustainability goals	3.98	0.820	12th
13	Adaptive shading systems	3.90	0.763	13th

Rankings recomputed from the reported means. Source: Authors' analysis, SPSS (2025).



Source: Authors' analysis (2025).

Figure 6: Mean level of agreement on the thirteen success factors (dashed line = 3.0 mid-point)

Table 8: Summary of the leading finding for each research objective

Research objective	Leading item	Mean	Key inference
Knowledge of strategies	Deep reveals	3.74	Familiarity is limited to simple fixed devices
Extent of integration	Deep reveals	2.80	Application is inadequate, every strategy sits below the midpoint
Barriers to integration	Cost implications	4.68	Commercial priorities dominate decision-making
Success factors	Energy savings	4.96	Framing shading in energy-cost terms is the strongest lever

5 DISCUSSION

The study provides empirical evidence on the current state of passive solar shading in Abuja's high-rise offices and its relationship with user comfort and sustainability. The best-known strategies, deep reveals (3.74) and horizontal louvres / light shelves (3.48), are the simplest fixed exterior devices, agreeing with findings that straightforward fixed typologies are better understood by professionals in tropical high-rise design. Integration, however, remained below 3.0 for every strategy, with deep reveals still highest (2.80). This disconnect between knowledge and practice echoes the literature's insistence that awareness alone is insufficient without enabling economic and regulatory conditions (Ochedi & Taki, 2021).

The strong ranking of cost implications (4.68) and developer priorities (4.66) as the leading barriers supports the argument that short-term commercial returns dominate Nigerian real-estate decision-making, consistent with Adegun (2017) on how the absence of enforceable energy codes creates a permissive environment for unsustainable design. On the other side, the prominence of energy savings (4.96) among success factors suggests that framing shading in measurable long-term cost and energy terms is the most compelling pathway to adoption, aligning with studies emphasising life-cycle analysis and performance-based incentives. The observations of Kingsway Tower, Tokiwabashi Tower and B-One reinforce the multi-dimensional nature of the problem: successful integration depends on context-specific facade systems, maintenance planning and institutional commitment, not on any single measure.

6 CONCLUSION

This study on passive solar shading in high-rise office buildings in Abuja underscores the importance of sustainable facade design. Most professionals are familiar with fixed exterior strategies, deep reveals (3.74), horizontal louvres / light shelves (3.48) and perforated metal screens (3.32) ranking highest, while dynamic and landscape-integrated strategies such as thermobimetal, kinetic shading and the Bosco Verticale typology are largely unknown. Integration remains low across all strategies, with only deep reveals showing relatively higher, though still limited, application. Cost implications, developer priorities, regulatory gaps and knowledge and expertise were the key barriers, while energy savings, climate responsiveness, indoor comfort and architectural expertise were the key enablers. Without wider adoption, high-rise offices will continue to face higher cooling costs, excessive energy use and missed opportunities for climate-responsive design. On this basis the study recommends:

1. Strengthening and enforcing the Building Energy Efficiency Code (BEEC) with mandatory passive-solar requirements;
2. Capacity-building and continuing professional development focused on fixed and adaptive shading systems;
3. Demonstration projects that quantify the energy and life-cycle cost savings of shading to influence developer priorities;
4. Supportive building codes and green-certification incentives that align short-term commercial interests with long-term sustainability; and
5. Professional awareness programmes within architectural and engineering firms on the benefits of context-specific passive solar shading.

Further research is suggested on the influence of passive solar shading on user comfort and energy performance in high-rise offices elsewhere in Nigeria and in other commercial building types.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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