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Geometrical and Material Considerations for External Shading Optimisation of Residential Buildings in Southeastern Nigeria: A Systematic Review

Chijioke Chinyere Onwuzuligbo[1]*, Chidiebele Ejikeme Joseph Uzoagba[2,3], Chukwunonso Obiefuna Umeora[1] and Nwanneka Chibuzo Mmonwuba[4]

[1]Department of Architecture, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria.
[2]Centre for Climate Change Adaptation and Mitigation Studies, African University of Science and Technology, Abuja, Nigeria.
[3]Materials Science and Engineering, African University of Science and Technology, Abuja, Nigeria.
[4]Civil Engineering Department, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria.

*Corresponding author: cuzoagba@aust.edu.ng

Abstract

The rising energy demand for cooling in residential buildings in Southeast Nigeria poses sustainability and energy security challenges. This study examines the optimisation of shading devices as a passive cooling strategy to enhance indoor thermal comfort by reducing solar heat gain in buildings. To explore the geometric and material properties of external shading devices and how they can be applied for enhanced results, identify the challenges to devices in Southeast Nigeria, and recommend context-specific architectural and environmental recommendations for the region. This scoping review employed thematic analysis to identify and summarise findings on considerations for optimizing external shading devices. The findings revealed that properly designed shading systems, which consider shape, orientation, dimensions, and material properties, can significantly improve building energy efficiency. However, barriers such as the high cost of advanced shading materials, weak regulatory enforcement, and limited technical expertise hinder widespread implementation. External shading performance is influenced by topography and climatic changes throughout Southeastern Nigeria, necessitating context-specific strategies for optimal shading efficacy. This study recommends integrating vernacular shading techniques, optimising orientation and overhang design, and exploring sustainable material innovations to enhance shading efficiency. Further research is needed to develop cost-effective, durable shading solutions suited to the region's climate and socioeconomic realities.

Keywords: *Passive designs, cooling strategies, thermal comfort, energy efficiency, tropical architecture, green buildings.*

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1. Introduction

The residential sector in Southeast Nigeria, as with national and global trends, is experiencing a growing electricity demand. National data indicate that residential buildings account for the highest electricity consumption at 58 %, followed by commercial and public services [1], [2]. Furthermore, national electricity demand has been increasing by approximately 1% per year since 2012 [3], largely due to rising temperatures, population growth, urbanisation, and the increasing need for household cooling [4]. Given the region's tropical climate, characterised by high temperatures, intense solar radiation, and high humidity levels, residential buildings require effective strategies to reduce cooling loads and enhance indoor thermal comfort [5], [6], [7].

A range of passive and active design strategies exists to improve energy efficiency in buildings. Passive approaches include optimising building orientation and layout, implementing shading devices and solar controls, utilising natural ventilation, and incorporating high-performance building materials and green roofs [8], [9], [10], [11]. On the other hand, active strategies involve energy-efficient (EE) heating, ventilation, and air conditioning (HVAC) systems, evaporative and desiccant cooling, and smart building management systems [8], [9], [10], [11]. Among these, shading devices stand out as highly effective yet often underutilised passive strategies that can significantly reduce solar heat gain and improve the thermal performance of residential buildings. This is particularly important because, as Munonye et al. [12] noted, thermal comfort is the indoor environmental component that gives building occupants in the tropics the greatest concern.

The increasing energy demand for cooling in residential buildings has raised concerns about sustainability and energy security in southeastern Nigeria. Air conditioning remains the predominant cooling method, exacerbating electricity consumption, straining the already overburdened national grid, and contributing to overall carbon dioxide (CO_2) emissions [4], [13]. While passive cooling strategies can help alleviate this burden, their proper adoption in the region remains non-existent, limited, or based on generic models rather than climate-specific design principles [14], [15]. According to the same sources, with inefficient or inadequately designed external shading solutions, residential buildings continue to miss the opportunity to enhance indoor comfort and reduce indoor heat gains passively.

External shading devices (ESDs) are intended to prevent glazed elements (glass windows and doors) from direct solar radiation by reducing glare and radiant solar heat gain (SHG) in climates with high cooling demands. This strategy is more effective than interior shading devices such as blinds. Radiation absorbed by surfaces in the room is emitted as long-wavelength radiation, which cannot escape back out through the glass because nearly all window glass is opaque to long-wavelength radiation [16]. This is because radiant solar heat gain occurs in the form of short wavelengths that can permeate through glass. This keeps the room's radiative solar gain contained, requiring a significant energy (electricity) input or natural ventilation to remove the heat gained [17].

The objective of this study is to explore the current state of knowledge in optimising these external shading devices. Specifically, this review identified the geometric and material properties of external shading devices and how they can be applied for enhanced results. It further identified the challenges in optimising the geometric and material properties of these devices in Southeast Nigeria. Finally, based on the findings, context-specific architectural and environmental recommendations are provided for residential buildings in the study area. Insights from this review will serve as a reference for architects, builders, and homeowners seeking to enhance the thermal performance and energy efficiency (EE) of residential buildings in Southeast Nigeria through the strategic use of shading devices.

2. Methodology

This systematic review focuses on the geometric and material properties of external shading devices for residential buildings in Southeast Nigeria. A total of 312 publications were identified through Google Scholar and other sources. After screening and removing duplicates (**Fig. 1**), 54 relevant publications (plus 3 undated web posts) published between 2007 and 2024 were included, ranging from relevant peer-reviewed articles, conference proceedings, and related product manufacturers' web pages. Data were categorized into four themes: geometric considerations, material properties, challenges, and recommendations. The findings highlight key design and material factors influencing shading effectiveness, regional barriers to optimisation, and context-specific suggestions for improved building performance and thermal comfort in hot, humid climates. The findings highlight key design parameters, material properties, and barriers to shading optimisation, offering context-specific recommendations for the region.

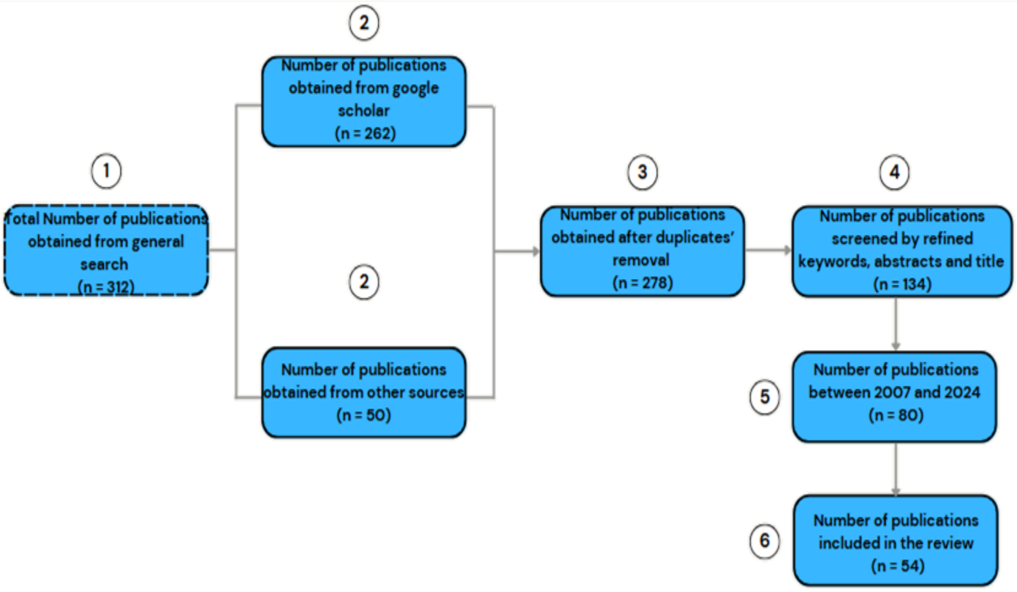

Figure 1: Flow Chart of the Systematic Review on the Geometrical and Material Considerations for External Shading Optimisation of Residential Buildings in Southeastern Nigeria

3. Results and Discussions

3.1 Geometric Considerations

The geometry of external shading devices (ESDs) significantly influences their effectiveness in reducing year-round solar heat gain (SHG) and maximising daylighting. Essential to the optimal functioning of external shading strategies include the following:

***Shape of the Overhang and Building Orientation*:** The shape of a shading device determines its effectiveness in keeping off solar radiation while allowing ventilation and the penetration of daylight. While horizontal shading devices (e.g., overhangs, louvres, and light shelves) are effective for north-facing and south-facing windows where the sun remains at high angles during the day in the tropics, vertical shading devices (e.g., fins, screens, and brise soleil) are more suitable for east- and west-facing facades, where the angle of the sun is lower in the morning and afternoon [18], [19]. Eggcrate shading devices, which integrate horizontal and vertical elements, provide better solar control, are optimal for facades exposed to varying sun angles, and perform best with nonoverlapping perforated blades [20]. They are also used for conditions where different times of the year warrant different shading needs. Parametric shading systems (e.g., perforated screens, and kinetic facades) use automated controls to adapt to changing solar positions (and other environmental stimuli) for optimised shading [21]. Because they are moveable, they can be used to control sunlight during the day as well as reduce heat losses at night, providing maximum shading as they fully cover the window.

Orientation and Sun Path: Building orientation influences the ability of shading devices to block solar radiation throughout the day, as the path of the sun dictates which façade receives the most direct sunlight. The north-south orientation benefits better from horizontal devices such as overhangs, whereas east–west-facing facades are effectively shaded by vertical fins or screens since the sun is at lower angles [18]. In terms of adjustability, fixed shading devices are designed based on annual sun path analysis but may not be effective in all seasons. Conversely, the angles of movable or operable shading devices (e.g., louvres, dynamic facades) can be adjusted manually or automatically to maximise their shading efficiency throughout the day [7], [22].

Dimensions of Shading Devices: The size and projection of shading devices determine their ability to block direct solar radiation while allowing sufficient daylight. The optimal depth of the projection depends on the window height and sun angle. For tropical designs, however, a common guideline for the window-to-wall ratio (WWR) is to use an overhang depth of at least 0.5 to 1.0 times the window height for effective shading [23]. However, given the post-Paris Agreement, signatories committed to climate action through their nationally determined contributions (NDCs) [24]. This implies that different national building codes may have different guidelines from those proposed in Kermani et al. [23].

Placement of Shading Devices: The positioning of shading devices relative to windows and building facades affects their efficiency. Overhangs are most effective when placed on north- and south-facing facades in tropical climates. Screens or fins are better suited for east- and west-facing walls, where solar angles vary significantly [7], [25]. While blocking unwanted sun rays, shading devices should not impede natural ventilation, which is vital for cooling in tropical climates. Considerations should be given to perforated shading devices, which enhance air movement while reducing direct sunlight penetration, as well as shading devices, which have ventilation gaps that allow cross-ventilation without excessive heat gain [7]. While blocking direct sunlight, shading should allow sufficient diffuse daylight to minimise artificial lighting needs, thus balancing the need for shading and daylighting [26].

3.2 Material Considerations

The material properties necessary for optimising sun shading include a balance in solar control, thermal comfort, durability, and aesthetics. The foremost considerations include the following:

***Thermal Conductivity*:** External shading reduces heat gain through solar radiation, allowing glazing with a higher solar heat gain coefficient (SHGC) to be selected without a significant negative impact. This reduces radiative heat gain, offering better thermal comfort conditions. The efficiency of the cooling system impacts the savings from shading. However, improperly designed shading may increase energy consumption due to increased solar heat gains [16]. Materials with low thermal conductivity, such as wood, bamboo, cement fibre boards, or aerated concrete, reduce heat transfer, thereby keeping indoors cool [13]. High-reflectivity (high albedo) materials such as light-coloured surfaces, polished metals, reflective coatings and cool roofing materials reduce solar heat absorption by reflecting a large portion of the incident solar heat radiation on the surface [27]. Low-emissivity materials, such as low-E glass, polished aluminium, and ceramic coatings, minimise heat re-radiation, keeping shaded areas cooler [13].

Thermal Mass: Materials with high thermal mass, such as concrete (used in conjunction with proper ventilation), adobe, rammed earth, and stone, absorb heat and release it gradually as temperatures drop, thus reducing sudden temperature fluctuations [28]. The direction of the released heat depends on factors such as material placement/exposure and ventilation. When such materials are used externally (exposed to the sun), they absorb heat during the day and gradually release it externally at night, thereby minimising indoor heat gain. If placed internally, the stored heat is gradually released back inside the building. This becomes a challenge in poorly ventilated spaces in hot climates, as heat is trapped indoors, causing discomfort [28], [29].

Durability and Maintenance: Materials for sun shading must withstand high temperatures, intense ultraviolet (UV) radiation, heavy rainfall, humidity, and strong winds (in coastal tropical regions), which can lead to degradation, corrosion, and biological growth (such as mould and algae) with minimal maintenance requirements, thus ensuring long-term efficiency and cost-effectiveness [7]. Materials such as UV-resistant polymers, treated wood, and powder-coated metals resist fading, brittleness and deterioration because of prolonged sun exposure, which is characteristic of the tropics

[7]. Other materials, such as stainless steel, aluminium, well-treated bamboo, weather-resistant wood, and fibre cement boards, are assessed for their moisture and corrosion resistance, whereas reinforced glass, high-tensile metal, and solid wood are resistant to the impact of strong winds [7].

Sustainability, Eco-friendliness and Localised Availability: Using sustainable and locally sourced materials for sun shading helps reduce environmental impact, lower costs, and support local economies. Locally available materials such as bamboo, thatch and timber have a lower carbon footprint than do energy-demanding alternatives (such as aluminium and concrete) because of reduced transportation emissions [30]. Similarly, indigenous materials are naturally adapted to local climates, thus providing better thermal performance. For example, rammed earth and adobe have high thermal masses and reduce heat gain due to intense solar radiation [31], [32]. Economically, supporting local industries creates jobs and promotes traditional construction knowledge, thus making them more affordable and easier to maintain and replace. In addition to their high thermal performance, breathability and sustainability in effectively reducing indoor heat gain, locally sourced materials, such as bamboo and thatch, are sun shading materials used for cultural and aesthetic reasons [33].

***Adaptive and Dynamic Shading Materials**:* These shading materials are adjusted to changing environmental stimuli to optimise thermal comfort and energy efficiency in indoor environments. Thermochromic and photochromic materials respond to changing levels of outdoor heat and light, respectively, by changing colour and transparency to reduce glare and excessive heat gain [34]. While smart fabrics with shape-memory alloys expand, contract, or reposition based on temperature changes or external stimuli, kinetic and responsive facades adjust dynamically and are sometimes controlled by sensors or programmable mechanisms [35]. For example, louvre sunshades made with shape-memory alloys close up during hot hours and open up during cool hours to regulate heat gain. PCMs such as paraffin wax, salt hydrates, and fatty acids are integrated into the fabrics of sunshades by lamination, microcapsules, or coatings [36]. They store and release heat to stabilise indoor temperatures, reducing overheating under direct sunlight [37], [38].

3.3 Optimisation Challenges in Southeast Nigeria

Despite global advancements in research on cooling energy reduction and improved energy efficiency in buildings, several challenges persist in optimising the geometric and material properties of building shading in Southeast Nigeria. This is particularly significant given the heavy energy demand contribution from the housing sector. In the context of southeastern Nigeria, the following potential challenges could prevent the optimisation of shading devices to reduce the heat load:

1. ***High Maintenance Cost of Locally Sourced Materials:*** natural, eco-friendly, and sustainable sun shading materials such as natural thatch are non-fire resistant, deteriorate under the elements, prone to pest invasion and require frequent maintenance, making them less of a choice in the Nigerian AEC industry [39], [40].
2. ***Non-Availability and High Cost of Materials:*** Some high-performance shading materials, such as electrochromic glass and advanced composites, are often expensive and currently unavailable in the region. Importing these materials increases costs and limits their adoption in households, the largest energy-consuming sector.
3. ***Construction and Maintenance Limitations:*** Advanced adaptable building design technologies such as dynamic facades and parametric shading require skilled labour during the construction and maintenance phases of such buildings, which may pose a challenge in a resource-constrained context.
4. ***Energy and Infrastructure Constraints:*** Unreliable power supply, which can hinder the adoption of energy-dependent and automation technologies such as motorised louvres, may not function optimally, leading to gross dissatisfaction [41], [42].
5. ***Weak Policies and Building Regulations:*** The lack of well-defined building codes and policies promoting climate-responsive shading strategies, as well as the absence of regulatory legal and policy frameworks, hinder the widespread adoption of optimised shading devices in new and existing buildings [41]. In Nigeria, where existing building codes have not been legislated, it has become difficult to enforce compliance and implementation.
6. ***Limited Data and Climate-specific Adaptation Challenges:*** The dearth of information and research gaps in empirical studies focusing on the performance of shading geometries and materials in Southeast Nigeria may pose a challenge to adapting sun shading techniques, particularly suitable for this context [43].

3.4 Context-Specific Architectural and Environmental Recommendations

Optimising sun shading in Southeast Nigeria requires a nuanced approach that considers the region's unique social, cultural, economic, and technological landscapes:

1. ***Indigenous Shading Strategies and Materials:*** Reintroduce and adapt traditional shading techniques (such as deep overhangs and verandas) and the use of locally sourced materials (such as raffia mats, bamboo, and clay-based screens), which are inherently adapted to the local climate and often have cultural significance [33], [44]. This reinforces the region’s cultural identity, promotes the use of locally available resources, and aligns with the existing architectural vernacular style. Furthermore, applying indigenous shading techniques and materials reduces reliance on expensive imported materials, reduces the embodied carbon resulting from the manufacture and transport of the shading material, and supports local artisans and industries, thus assisting in advancing the technological frontiers of the nation [45].

2. ***Locally Sourced Thermal Mass Materials Utilisation:*** Materials such as laterite bricks, clay blocks, or stabilised rammed earth, given their high thermal mass, absorb and store heat during the day and release it later as

temperatures drop, making them suitable for sun shading when used outdoors. These materials are readily available, cost-effective, and align with traditional building practices [46]. The principle of using earthen materials for thermal mass, a long-standing practice in traditional Nigerian architecture, is now being implemented in contemporary eco-friendly buildings globally to achieve temperature regulation [45].

3. ***Integrated External Vegetative Shading:*** Green facades and roofs are increasingly used in urban environments to reduce cooling loads, increase energy efficiency, and improve air quality through canopy evapotranspiration and shading [47]. This also serves the purpose of enhancing aesthetics and increasing biodiversity [33]. These bio-shades can be incorporated through climbing plants (and the supporting trellis), and trees can be strategically planted.

4. ***Optimised Orientation and Overhang Design:*** Proper orientation and overhang design are fundamental passive cooling strategies that do not rely on mechanical systems to significantly reduce solar heat gain [29]. In the tropics, buildings should be aligned with longer facades facing the north–south axis to minimise exposure to the harsh east–west sun [5]. The east and west walls and windows should be shaded further with integrated overhangs, deep eaves, and verandas.

5. ***Perforated Screens and Breathable Materials:*** Perforated screens, such as perforated lightweight concrete shells and metal screens, create a balance between shading and ventilation while offering a degree of privacy and security within a space [48], [49]. Breathable materials, such as woven palm mats and bamboo slats, offer good ventilation and UV protection while offering varied resistance to deterioration from weather elements [50]. Woven mats are commonly made from raffia, bamboo, palm fronds, grass, and straw and are still used traditionally as shading devices [51]. Brise soleil, on the other hand, is commonly made from aluminium and timber [52].

6. ***Integration of Courtyards and Transitional Spaces:*** Courtyards, which are typical in the region’s vernacular architecture, create favourable microclimates that enhance the performance of shading devices. Similarly, transitional spaces such as verandas and covered walkways act as thermal buffers between the hot exterior and the more controlled interior spaces. Additionally, courtyards and transitional spaces provide valuable social spaces for communal cohesion [53].

7. ***The Use of Light-Coloured Exterior Finishes:*** Light colours reflect a high percentage of solar radiation, greatly reducing the amount of heat absorbed by the building [27]. This is a very cost-effective method of reducing heat gain. Exterior walls and roofs should therefore be finished with high solar reflectance index (SRI) materials such as white or light-coloured paint or plaster. This can reduce the cooling load in air-conditioned spaces and improve thermal comfort in non-air-conditioned spaces [16].

8. ***State-level Climatic Considerations***: While the recommendations may serve as a baseline for southeastern Nigeria given the comparatively similar culture, availability of local materials, and technological limitations, variations in topography and microclimatic conditions such as those observed between Enugu and other southeastern states can influence the effectiveness of sun shading devices [54], hence the need for state-level climatic considerations.

4. Conclusion

While the optimisation of sun shading devices presents a promising solution for reducing cooling energy demand and improving indoor thermal comfort in hot Tropical Southeast Nigeria, it is important to note the effectiveness of integrating passive cooling strategies with mechanical ventilation, as demonstrated in similar tropical contexts. Additionally, drawing from vernacular architectural designs, such as deep overhangs and verandas, highlights the potential of culturally and climatologically relevant solutions for shading optimisation, as in other geographies. However, certain limitations of this review necessitate cautious interpretation. Although the findings are instructive, they may not be directly applicable across all parts of Southeast Nigeria, as variations in topography and microclimatic conditions, such as those observed between Enugu and other southeastern states, can influence the effectiveness of sun shading devices. Furthermore, insights from this review highlight significant research gaps that require further investigation. Further studies and experiments are needed to re-engineer natural thatch and other high-maintenance materials without incurring the undesired effects associated with their synthetic counterparts. Similarly, there is still a scarcity of information on optimisation parameters for perforated screens for energy efficiency in the tropics. Addressing these gaps requires a multidimensional approach that considers not only the properties of shading devices but also the regulatory and legal enforcement of climate-responsive building codes and policy interventions, the integration of vernacular and modern passive design principles, capacity building, and increased public awareness.

Declarations

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