Evaluating the Impact of Different Shading Devices on Daylighting and Visual Comfort in Nigeria's Temperate Dry Climate

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Abstract

Architects and researchers have employed various shading devices to mitigate glare and overheating in buildings. For instance, vertical shading devices are often recommended for eastern and western facades, while horizontal shading devices are preferred for northern and southern facades. Additional recommendations include overhang projection factors and egg-crate shading devices. This research aims to evaluate the influence of various shading devices on daylighting for indoor visual comfort in the temperate dry climate of Nigeria. The study assessed horizontal overhangs, horizontal fins, horizontal angle fins, horizontal louvers, egg-crate, and vertical fin shadings by analyzing their average Daylight Autonomy (DA) values and percentage DA reduction. Data was collected through simulations of a prototype single-bank building using Google SketchUp 2022 and the OpenStudio simulation tool, conducted on hypothetical sites devoid of surrounding buildings and trees in Zaria, Nigeria. The data was analyzed using MANOVA, bar charts, column charts, graphs, and tables, with a significance threshold of 0.05. The research assumed that for a room to be visually comfortable, the shading device must achieve a minimum DA value of 60% and a DA percentage reduction of less than 40%. The findings revealed statistically significant differences in the performance of the various shading devices for daylighting and visual comfort: DA ($F(5, 18) = 217.64$, $p < .000$, partial $\eta2 = .984$) and rDA ($F(5, 18) = 241.65$, $p < .0000$, partial $\eta2 = .85$).

Keywords: Daylight autonomy, DA percentage reduction, Shading device, Single-banked building, Visual Comfort

INTRODUCTION

There are broadly two types of solar shading devices: external and internal. External solar shading devices have proven to be more effective in reducing heat gains, glare, and energy demands across various climates (Dakheel & Aoul, 2017). Fixed shading devices, which can be horizontal, vertical, or a combination of both (commonly called "egg-crate"), offer several advantages over movable shading. These advantages include being relatively inexpensive, easy to install and maintain, having a longer lifespan, and consistently maintaining their shading effect over time (Lechner, 2014). Consequently, most buildings still utilize fixed shading designs.

Various studies have documented the performance of different shading devices in reducing glare and overheating indoors. For instance, Syma (2015) observed a 5% to 15% reduction in indoor energy use depending on the type of shading device. According to Lee, Han, and Lee (2017), horizontal louvers are particularly effective for the northern and southern facades, while vertical louvers are recommended for the eastern and western facades. Additional research has suggested optimal overhang projection factors and the efficacy of egg-crate shading devices.

This research aims to evaluate the influence of various shading devices on daylighting for indoor visual comfort in the temperate dry climate of Nigeria. Specifically, it assesses the performance of horizontal overhangs, horizontal fins, horizontal angle fins, horizontal louvers, egg-crate, and vertical fin shadings by analysing their average Daylight Autonomy (DA) values and percentage reductions in DA.

The hypotheses for this study are as follows:

a) Null Hypothesis (H0): The mean performance of all shading devices is significantly the same for all building elevations in the temperate dry climate of Nigeria.

b) Alternative Hypothesis (H1): The mean performance of at least one shading device differs significantly for one or more building elevations in the temperate dry climate of Nigeria.

Concept of Comfort

The concept of comfort is multifaceted, with diverse connotations depending on the context. Chappells and Shove (2004) identified six different contexts of comfort: technology and society, the indoor environment, the outdoor climate, health and wellbeing, culture and social convention, and climate change. Kolcaba (2010) described comfort as existing in three forms: relief, ease, and transcendence. She also identified four contexts in which comfort can occur: physical, psycho-spiritual, environmental, and sociocultural. Holistic comfort, according to Kolcaba (2010), is the immediate experience of being strengthened through having the needs for relief, ease, and transcendence met in these four contexts.

Studies have shown that people prefer to live within a wider temperature range (ASHRAE Standard 55, 2015), which is achievable in a natural environmental setting. Therefore, humans often prefer natural indoor environmental comfort to artificial settings, considering factors such as temperature, relative humidity, and daylighting. Literature reviews indicate that thermal comfort and daylighting are the main parameters in determining passive indoor environmental comfort in tropical climates (Sakellaris et al., 2016).

Daylight refers to the total direct and indirect light from the sun during the daytime, affecting the visual and non-visual comfort of building occupants. Daylighting involves the controlled use of natural light in and around buildings (Reinhart, 2014). The effects of daylight on building users can be categorized into two types:

a) ***Visual effects****:* Enable people to see and interact with the world, enhancing human performance, health, well-being, and productivity (Edwards & Torcellini, 2002).

b) ***Non-visual effects:*** Impact human behavior, such as alleviating seasonal depression (Rosen et al., 1990), reducing anxiety and depression (Öztürk, Moreno & Lowden, 2017), and reducing the risk of cardiovascular disease (Yamada et al., 2015).

However, uncontrolled daylight can cause distracting glare and heat, leading to temperature imbalances in a room. Researchers have explored various methods to control daylight in tropical buildings, such as reducing apertures for solar penetration, using glazing, and employing shading devices as shown in fig. 1.

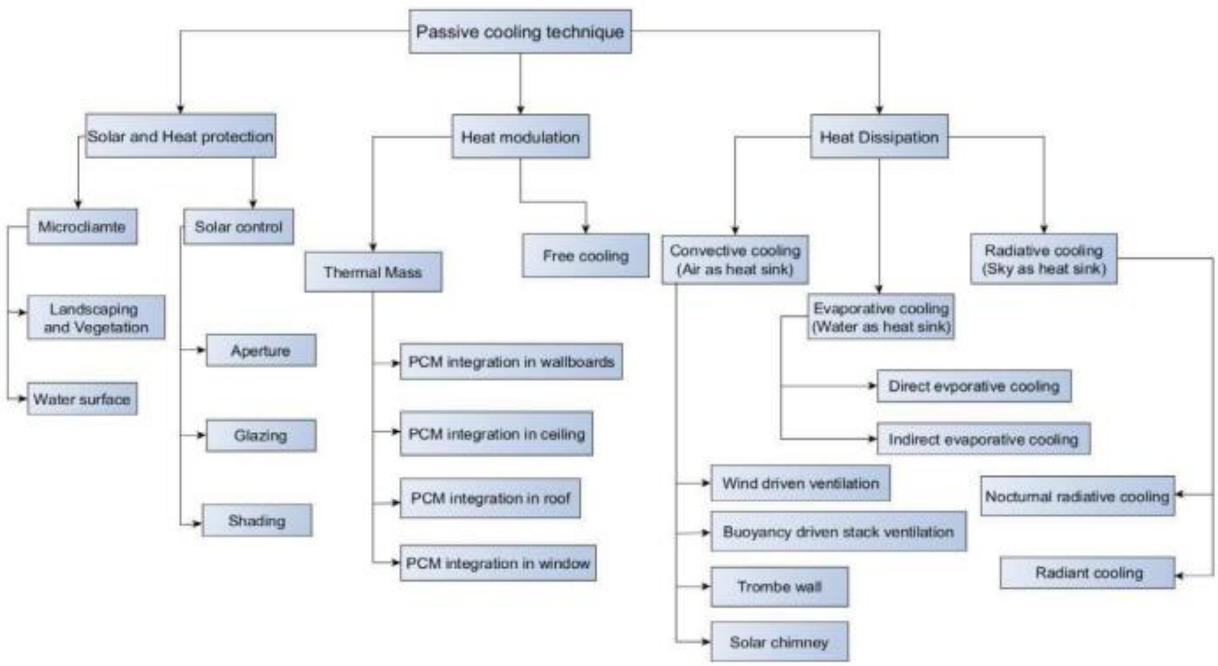

Figure 1. Classifications of Passive Cooling Techniques
Source; Bhamare, Rathod, & Banerjee, (2019).

Climate classifications can be grouped into three essential types: empiric, genetic, and applied climate classifications (Guglielmetti, Macumber, & Long, 2011), depending on the type of data used. Köppen's and Miller's classifications were based on vegetation, Thornthwaite's on agriculture, and Atkinson's on thermal comfort. Koenigsberger, Ingersoll, Mayhew, and Szokolay (2013) noted that most climate categorizations based on human comfort have their origins in Atkinson's (1953) classification, such as those by Koenigsberger, Komolafe, Agwal, Olufowobi, Szokolay, Ogunsote, and Prucnal-Ogunsote, and Mobolade and Pourvahidi (2020).

This research adopts the Mobolade and Pourvahidi (2020) climate classification, as it uniquely considers temperature, relative humidity, mean radiant temperature, and wind velocity. Therefore, its classification is based on the Comfort and Bioclimatic Approach as shown in fig. 2.

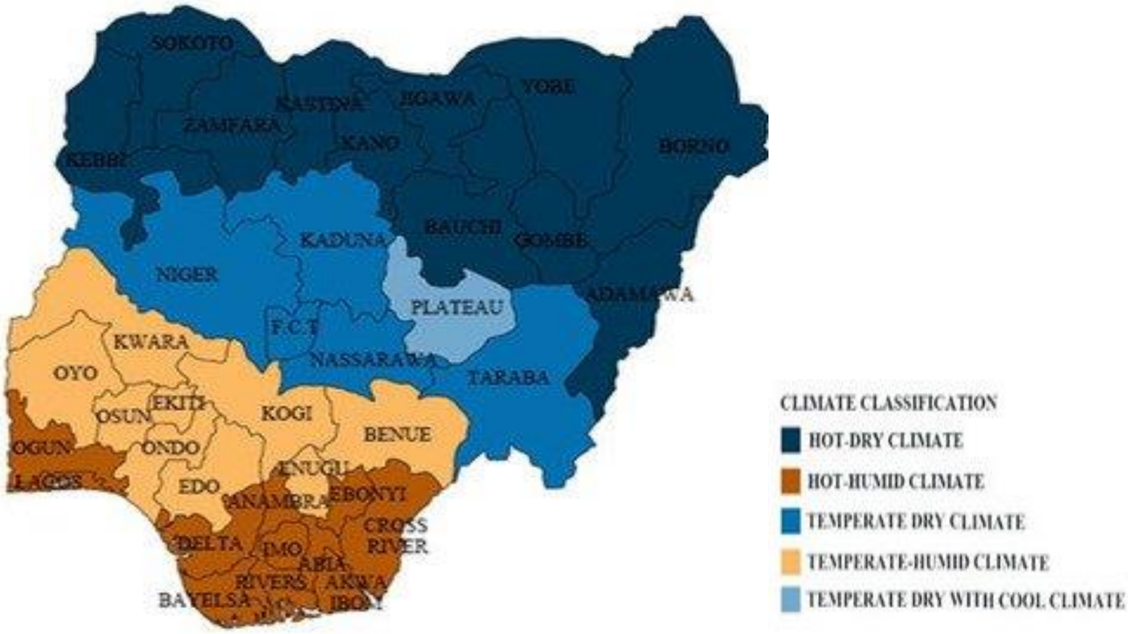

Figure 2: Classification of the Nigerian climate Mobolade and Pourvahidi (2020).

METHODOLOGY

To evaluate the performance of six different types of shading devices on daylighting for visual comfort, as the most commonly used shading devices in the temperate dry climate of Nigeria, the following devices were analyzed: horizontal overhang, horizontal fin, horizontal angle fin, horizontal louvers, egg-crate shading, and vertical fin shading devices. A quantitative research design and an explorative approach were employed, utilizing an experimental research strategy through simulation.

Data was collected from simulations of a prototype single-bank building using Google SketchUp 2022 and the OpenStudio simulation tool. These simulations were conducted on hypothetical sites devoid of surrounding buildings and trees in Zaria, Nigeria. The collected data was then analyzed using MANOVA, bar charts, column charts, graphs, and tables, with a significance threshold of 0.05.

The research assumed that, for a room to be visually comfortable, the shading device must achieve a minimum recommended Daylight Autonomy (DA) value of 60% and a DA percentage reduction of less than 40%. Hence, the performance of the shading devices was categorised as in table 1.

These categories helped in systematically assessing and comparing the performance of each shading device in terms of its impact on daylighting and visual comfort.

Table 1: Performance Categories of Shading Devices Based on Daylight Autonomy (DA) Percentage Reduction and Minimum DA Value (≥ 60%).

Performance Category	DA Percentage Reduction
Low	0-9
Medium	10-19
Adequate	20-29
Satisfactory	30-39
Over	>40

RESULTS AND DISCUSSION

The results indicate that the best shading device for all four elevations (northern, southern, eastern, and western facades) is the *Horizontal Fin*, followed by the *Vertical Fin Shading* device though in different levels of performance (table 1). For example, the performance of Horizontal Fin is found to be "*Satisfactory"* in the northern façade with DA percentage reduction of 20 % to 29% and DA ≥ 60%; "*medium*" in the southern facade with DA percentage reduction of 17% and DA of 82.3%; and "*adequate"* in the eastern and western façades with DA percentage reduction within the range of 20 % to 29% and DA ≥ 60% as indicated in Figure 3.

Table 1. Performance of various shading devices for visual comfort in the temperate dry climate of Nigeria.

S/No	Shading devices	North		South		East		West	
		DA %	$_r$DA %	DA %	$_r$DA %	DA %	$_r$DA %	DA %	$_r$DA %
1	Horizontal Overhang	96.6	2.1	98.9	0.6	97.3	2.2	98.2	1.4
2	Horizontal Fin Shading	68.4	30	82.3	17	78	21.6	77.6	22
3	Horizontal Angle Fin Shading	3.5	96	11.3	88.6	13	86.9	11	88.1
4	Horizontal Louvers	94.8	3.9	98.3	1.2	96.8	2.7	97.3	2.3
5	Egg-Crate Shading	21.3	78	34.3	65.6	40.2	59.6	37.2	62.5
6	Vertical Fin Shading	77.3	21.6	88.5	11	84.1	15.4	84.1	15.5

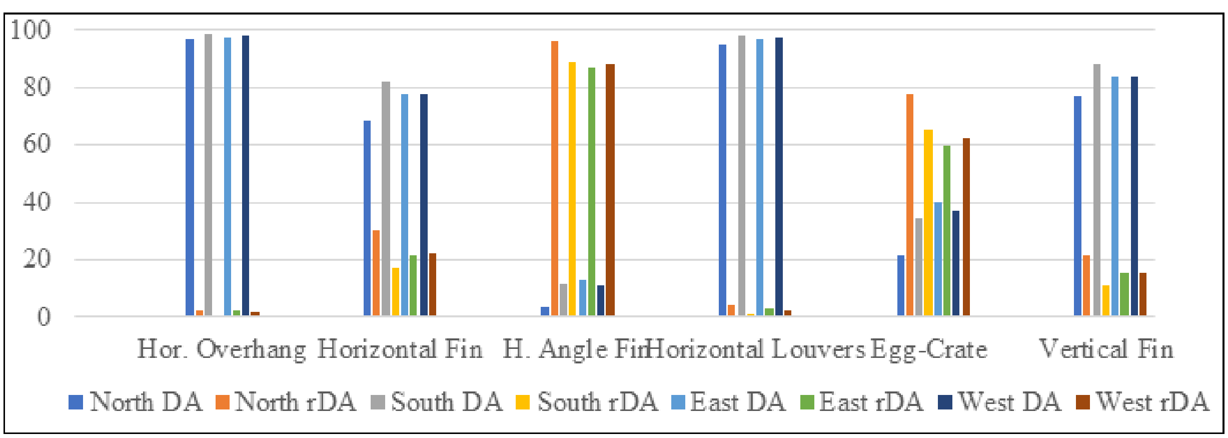

Figure 3. Performance of various shading devices for visual comfort in the temperate dry climate of Nigeria.

Performance of overhang shading is significantly low across all elevations, with a DA percentage reduction of less than 2.5% and DA ≥ 96.6%. Conversely, horizontal angle fin and egg-crate shading devices have demonstrated superior performance, achieving a DA percentage reduction above 59% and DA less than 45% in all facades, as illustrated in Figure 2. The horizontal louvers shading device shows a lower performance, with a DA percentage reduction of less than 4% and DA ≥ 96.8% across all elevations.

Hypothesis Testing

The null hypothesis (H0) posits that the mean performance of all shading devices in a building is equal across all building elevations in the temperate dry climate of Nigeria. The alternative hypothesis (HI) suggests that the mean performance of shading devices varies significantly across at least one building facade in the temperate dry climate of Nigeria.

The data were examined for skewness and kurtosis, falling within the acceptable range defined by George and Mallery (2010). A one-way MANOVA was conducted to analyze the performance of various shading devices, indicating significant differences across elevations in one or more visual comfort indicators. The homogeneity of variance-covariance matrices was confirmed using Box's Test of Equality of Covariance Matrices, yielding a non-significant result (Box’s M = 26.840, $p = .212$), indicating equal covariance matrices across groups for MANOVA.

The MANOVA revealed a statistically significant difference, $F(10, 34) = 31.71$, $p < .000$; Wilk’s $\Lambda = .009$, partial $\eta 2 = .903$. Post hoc tests were conducted to determine specific differences among the levels of the independent variable due to the presence of more than two levels. Levene’s F test confirmed homogeneity of variance assumptions for all variables.

Subsequent one-way ANOVAs on each visual comfort indicator showed statistically significant results for DA ($F(5, 18) = 217.64$; $p < .000$; partial $\eta 2 = .984$) and rDA ($F(5, 18) = 241.65$; $p < .000$; partial $\eta 2 = .85$).

CONCLUSION

These findings highlight the importance of selecting shading devices based on their individual performance characteristics relative to building orientation and elevation. This study highlights the significant variability in shading device effectiveness across different facades, emphasizing the necessity to evaluate their performance specific to each elevation before implementation. Such considerations are central for optimizing visual comfort and enhancing energy efficiency in buildings located in temperate dry climates.

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