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Passive Solar Control Strategies in Hot Climates: An Assessment of Shading Device Efficiency at Federal Polytechnic, Mubi

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ABSTRACT :

Hot climatic zones such as Mubi, Adamawa State, Nigeria, experience intense solar radiation and high ambient temperatures for most of the year, placing considerable thermal stress on building occupants and increasing reliance on mechanical cooling. Passive solar control through shading devices offers a low-energy, cost-effective alternative for regulating indoor thermal environments. This study assesses the effectiveness of shading devices deployed on selected buildings within Federal Polytechnic, Mubi Campus, evaluating their influence on indoor air temperature, solar heat gain, and occupant thermal comfort. Literatures were reviewed to analyze and recommend appropriate shading techniques for each elevation of randomly selected 10 buildings within the campus. A descriptive survey and comparative field-assessment design was adopted, combining on-site temperature measurement, building orientation analysis, and structured questionnaires administered to staff and students, were scored using Likert scale. Findings indicate that horizontal overhangs and vertical louvers on west- and east-facing facades produced measurable reductions in indoor temperature and glare relative to un-shaded openings as found in; Polytechnic Library & Engineering complex have effective shading. While, ICT & School Clinic had lowest existing shading elements were found to be undersized or poorly oriented relative to the sun-path geometry of the site. It was observed whether climatic principles were generally overridden by the requirement of proportion, symmetry & aesthetic by Architects in Mubi. The study recommends climate-responsive shading design guidelines, informed by solar geometry and local material availability, for future institutional building projects in hot climatic zones of Nigeria.

Keywords: *Passive design, solar shading, thermal comfort, Hot-climate, sustainable architecture; Mubi*

1.0 Introduction

Buildings in hot-arid regions are subjected to prolong and intense solar radiation, particularly during the dry season, resulting in elevated indoor temperatures, occupant discomfort, and increased dependence on artificial cooling systems [1]. Mubi, located within the Sudan-Sahel climatic belt of north-eastern Nigeria, records ambient temperatures frequently exceeding 35°C during peak months, with intense direct and diffuse solar radiation striking building envelopes for most of the day [2]. In such contexts, passive design strategies particularly solar shading represents a fundamental, energy-independent means of moderating indoor thermal conditions.

Shading devices, whether horizontal overhangs, vertical fins, louvers, or vegetative screens, function by intercepting direct solar radiation before it reaches glazed or opaque building surfaces, thereby reducing conductive and radiant heat [3]. Their effectiveness, however, is highly sensitive to design parameters such as depth, angle, orientation, and material properties, and a poorly designed device may offer negligible thermal benefit despite its presence [4]. Many institutional buildings in northern Nigeria, including those at Federal Polytechnic, Mubi, were designed with limited attention to solar geometry, resulting in shading elements that are often ornamental rather than functional.

This study therefore examines the effectiveness of existing shading devices across selected buildings at Federal Polytechnic, Mubi, with a view to establishing the extent to which they mitigate solar heat gain and enhance indoor thermal comfort, and to proposing evidence-based design improvements suited to the local hot-arid climate.

1.1 Statement of the Problem

Despite the evident climatic demand for effective solar control, many buildings within the Federal Polytechnic, Mubi campus continue to exhibit poor thermal performance, evidenced by occupant complaints of overheating, glare, and heavy reliance on electric fans and air-conditioning units. This suggests that where shading devices exist, they may be inadequately designed, incorrectly oriented, or insufficient in scale to counter the intensity of solar radiation characteristic of the region. There is limited empirical documentation assessing the actual performance of these devices, creating a gap between design intention and measured thermal outcome.

1.2 Aim and Objectives

The aim of this study is to assess the effectiveness of shading devices as a passive solar control strategy in the hot-arid climate of Mubi, using Federal Polytechnic, Mubi as a case study. The specific objectives are to:

i. examine the types and configurations of shading devices present on selected campus buildings;
ii. evaluate the influence of these devices on indoor air temperature and solar heat gain relative to un-shaded conditions;
iii. assess occupant perception of thermal comfort in shaded and un-shaded spaces; and
iv. recommend climate-responsive shading design guidelines for future institutional buildings in similar hot-arid contexts.

1.3 Significance of the Study

The findings of this study will provide empirical evidence to guide architects, planners, and facility managers within tertiary institutions in hot-arid Nigeria toward more climate-responsive design decisions. It also contributes to the growing body of literature on passive design performance in Sub-Saharan African contexts, where such empirical, site-specific data remain relatively scarce.

2.0 Literature Review

2.1 Passive Solar Control and Shading Devices

Passive solar control refers to non-mechanical architectural strategies employed to regulate the amount of solar radiation admitted into or excluded from a building, thereby moderating indoor thermal conditions without reliance on active energy systems [5]. Shading devices constitute one of the most widely applied passive strategies, and are generally classified into horizontal devices (overhangs, canopies), vertical devices (fins, louvers), and combined, curvilinear, or movable systems [6]. The performance of a shading device is governed largely by the sun-path geometry relevant to the building's latitude, meaning that devices effective on south- or north-facing facades may be entirely ineffective on east- or west-facing ones, where low-angle morning and afternoon sun requires deeper vertical elements rather than horizontal overhangs [2].

[4] Demonstrated, through dynamic energy simulation, that optimal overhang depth varies considerably with climate subtype, and that undersized or generically applied overhangs deliver substantially less cooling benefit than depths calibrated to local solar geometry. Similarly, [3] found that external movable shading devices reduced cooling demand by more than 60%, compared with only about 25% for interior shading such as venetian blinds, since heat intercepted outside the building envelope does not contribute to internal heat gain, whereas heat absorbed by interior shading is largely re-radiated into the space.

2.2 Thermal Comfort in Hot-Arid Climates

Thermal comfort is a subjective condition of satisfaction with the surrounding thermal environment, influenced by air temperature, radiant temperature, humidity, air movement, clothing, and metabolic activity [7]. In hot-arid climates, comfort is particularly difficult to achieve passively because of the combination of high daytime temperatures, intense solar radiation, and low humidity, which together elevate both convective and radiant heat loads on occupants [1]. The study of Nigerian university buildings established that indoor-outdoor temperature differentials were strongly influenced by building envelope characteristics, including shading and ventilation provisions, reinforcing the relevance of passive envelope interventions in the Nigerian climatic context [8].

2.3 Solar Geometry and Building Orientation

The effectiveness of any shading device cannot be divorced from building orientation, since solar altitude and azimuth angles vary considerably through the day and across seasons [2]. For locations near the tropics such as Mubi (latitude approximately 10°N), the sun is high overhead for much of the year, making horizontal shading relatively effective on north- and south-facing openings, while east and west facades receive low-angle radiation that horizontal devices cannot adequately intercept, necessitating vertical fins, curvilinear, or combined shading solutions [10] .

2.4 Gaps in Existing Studies

While considerable research exists on shading device performance in tropical and temperate contexts, site-specific empirical assessments within Nigerian tertiary institutions, particularly in the hot-arid north-east remain limited. This study addresses this gap by providing a localized, evidence-based assessment of shading effectiveness at Federal Polytechnic, Mubi.

3.0 Methodology

3.1 Research Design

The study adopted a descriptive survey and comparative field-assessment design, combining quantitative field measurement with a structured questionnaire survey. This mixed method approach allowed physical thermal performance data to be triangulated with occupant perception, providing a more holistic assessment of shading effectiveness [8] . Ten buildings were selected conveniently for the study.

Data were collected base on the essential elements of the research using checklist at Likert scale 0f 0 – 5. This was done by formulation of ten (10) questions, each of which was answered using the rating scale. Data were analyzed using descriptive statistics.

The shading techniques considered are shown below with acronyms assigned to each variable to simplify data tabulation. These variables were examined in each case study to know the extent to which they are applied.

Shading of building surfaces techniques:

- **i.** Is the shading device on West façade Vertical? (SHD W)
- **ii.** Is the shading device on East façade Vertical? (SHD E)
- **iii.** Is the shading device on North façade horizontal? (SHD N)
- **iv.** Is the shading device on South façade horizontal? (SHD S)
- **v.** Is the size of shading device on West façade adequate to provide protection especially when the sun is overhead? (SHD SZ W)
- **vi.** Is the size of shading device on East façade adequate to provide protection especially when the sun is overhead? (SHD SZ E)
- **vii.** Is the size of shading device on North façade adequate to provide protection especially when the sun is overhead? (SHD SZ N)
- **viii.** Is the size of shading device on South façade adequate to provide protection especially when the sun is overhead? (SHD SZ S)
- **ix.** Is the roof overhang wide enough to provide protection? (RF EXT)

Is shading using plant? (SHD PLT)

3.2 Study Area

Federal Polytechnic, Mubi is located in Mubi North Local Government Area, Adamawa State, north-eastern Nigeria, within the Sudan savanna climatic zone characterised by a long dry season, intense solar radiation, and high diurnal temperature variation.

The selected buildings with their acronyms for easy tabulation are shown in Table: 1

Table: 1 Case study and their acronym

S/No	Description	Acronym
1	Polytechnic Clinic	PCL
2	Business Department	BAM
3	Engineering Complex	ENG
4	Prof. Jibril Amin Library	LIB
5	Information and Communication Technology Centre.	ICT
6	Science Laboratory Technology	SLT
7	Physical Planning Directorate	PPD

8	Architectural Technology Department	ARC
9	Computer center	COM
10	Works Directorate Department	WDD

Source: Authors field work (2023).

3.3 Sampling and Building Selection

Ten academic and administrative buildings across the campus were purposively selected to represent a range of orientations (north, south, east, and west-facing facades) and shading device types (horizontal overhangs, vertical louvers, and un-shaded control openings). Within these buildings, a structured questionnaire was administered to 120 staff and students using a purposive sampling technique targeting occupants of the selected class rooms.

3.4 Data Collection Instruments

i. Field temperature measurement: Digital thermometers and infrared surface-temperature guns were used to record indoor air temperature and internal wall/window surface temperature at three intervals daily (9:00am, 1:00pm, and 4:00pm hours) over a two-week period, for both shaded and un-shaded class rooms.

ii. Building and device survey: Physical measurement of shading device dimensions (projection depth, angle, material), combined with documentation and orientation mapping using a compass.

iii. Structured questionnaire: A closed-ended instrument capturing occupant perception of indoor temperature, glare, and general thermal comfort on a five-point Likert scale.

3.5 Method of Data Analysis

Quantitative temperature data were analyses using descriptive statistics (means and standard deviations) and presented in comparative tables and charts across shaded versus un-shaded conditions. Questionnaire responses were analyses using simple percentages and mean scores, in line with standard practice in comparable environmental-performance studies [7].

4.0 Results and Discussion

4.1 Indoor Temperature: Shaded versus Un-shaded Rooms

Table 1 presents the mean indoor air temperatures recorded across shaded and un-shaded rooms

As shown in Table 2, the difference between shaded and un-shaded rooms widens through the day, peaking at the 1:00pm measurement interval when solar altitude is highest. This pattern is consistent with findings by [3], who observed that shading benefit is most pronounced during peak solar hours, when unmitigated direct radiation contributes most substantially to envelope heat gain.

Table: 3 Showing Shading Performances

S/N	BLG	SHD (W)	SHD (E)	SHD (N)	SHD (E)	SHD (SZ.W)	SHD (SZ.E)	SHD (SZ.E)	SHD (SZ.S)	RF EXT	SHD PLNT	TOTAL SCORE	% SCOREE
1	**PCL**	2	2	1	1	0	0	1	1	3	0	11	22
2	**BAM**	3	3	3	3	2	2	2	2	1	1	22	44
2	**ENG**	4	4	4	4	2	2	4	4	4	1	35	68
4	**LIB**	4	4	4	4	4	4	4	4	4	2	38	76
5	**ICT**	3	3	0	0	1	1	1	1	1	1	12	24
6	**SLT**	2	2	2	2	3	3	2	2	1	1	20	40
7	**PPD**	2	2	2	2	2	2	2	2	3	2	21	42
8	**ARC**	3	3	3	3	3	3	2	2	2	2	26	52
9	**COM**	2	2	1	1	1	1	2	2	3	1	16	32
10	**WDD**	2	2	2	2	2	2	2	2	3	4	23	46
MEAN		3	3	2	2	2	2	2	2	3	2	22	45
SD		1.0	1.0	1.3	1.3	1.1	1.1	1.0	1.0	1.3	1.2	8.4	16.5%

Source: Authors field work (2023)

4.2 Performance by Orientation and Device Type

Buildings with vertical louvers on west-facing facades recorded lower afternoon indoor temperatures than those relying solely on horizontal overhangs, a pattern consistent with the sun-path expectation that horizontal devices are less effective against the low solar angles typical of east and west exposures [2] ;[4]. Conversely, horizontal overhangs performed comparatively well on south-facing openings, where the sun remains relatively high for much of the day. Several existing overhangs across the campus were observed to have insufficient projection depth relative to window height, reducing their shading coefficient below what would be required for effective mid-day solar exclusion.

4.3 Occupant Perception of Thermal Comfort

Questionnaire responses indicated that a majority of occupants in shaded rooms reported greater satisfaction with indoor thermal conditions and reduced glare compared to occupants of un-shaded rooms, who more frequently reported reliance on electric fans and window coverings as coping mechanisms. This finding aligns with [8], who similarly linked occupant-reported discomfort in Nigerian buildings to envelope-level deficiencies rather than solely to outdoor climatic severity.

4.4 Discussion

Collectively, the findings suggest that shading devices at Federal Polytechnic, Mubi do contribute measurably to indoor thermal moderation, but their effectiveness is inconsistent across the campus due to variation in device depth, orientation-appropriateness, and material choice. This inconsistency reflects a broader pattern noted in the literature, whereby shading elements are frequently applied for aesthetic or symbolic reasons rather than derived from solar-geometric analysis specific to the building's orientation and [2], [5].

The effectiveness of shading techniques in Table 3; 8 out of the 10 buildings selected scored below 50%. Type of shading devices on each facade has a mean score of 2 with no difference among all the facades. Shading using roof overhang has a mean score of 3. It indicate that shading is one the most important passive cooling techniques at it can eliminate the need for the other techniques if properly applied. According to [10], when buildings internal and external solar gains are sufficiently reduce, a lean acclimatization concept can be developed. On shading using plants (SHD PLNT) shows that 9 out the 10 buildings have failed with the exception of WDD, all the road have either tarred road, concrete paving, sand or a few combination of all these landscape elements around. Very few have traces of grass lawn. Trees are few and scattered while absent in some structures. During peak summer days the average temperature of walls shaded by trees or a combination of trees and shrubs can be reduced up to 150k. Climbing vines can reduce to temperature by up to 120k [10]. The results reinforce the argument that passive shading strategies, when properly calibrated to local solar geometry, can meaningfully reduce reliance on active cooling in hot-arid institutional buildings.

5.0 Conclusion and Recommendations

5.1 Conclusion

This study assessed the effectiveness of shading devices as a passive solar control strategy within the hot-arid climate of Mubi, using Federal Polytechnic, Mubi as a case study. The evidence indicates that appropriately designed and oriented shading devices can produce meaningful reductions in indoor temperature and improvements in occupant thermal comfort, while poorly configured devices offer limited benefit. Orientation-specific design, rather than generic application of shading elements, emerges as the critical determinant of performance. Architects have knowledge of shading techniques but they concentrate more on aesthetics and functionality. Its concluded that most of the shading devices are designed to meet more of aesthetic requirements rather than shade. Vegetation and trees in particular effectively shade and reduce heat gain. They also cause pressure differences thereby increasing and decreasing air speed or directing air flow. Therefore, they can direct air into a building or deflect it away. Trees ,plants and shrubs absorbs radiation in the process of photosynthesis and can be used to cut off east and west sun which can results in cooling of the environment.

5.2 Recommendations

Based on the findings, the following recommendations are proposed:

i. Future institutional buildings within the Federal Polytechnic, Mubi campus, and similar hot-arid contexts, should adopt shading device designs derived from solar-path analysis specific to each facade orientation, rather than uniform or purely aesthetic treatments.

ii. Vertical louvers or combined egg-crate devices should be prioritised on east- and west-facing openings, while horizontal overhangs of adequate projection depth should be applied to north- and south-facing openings.

iii. Existing under-performing shading devices identified in this study should be retrofitted or extended to meet minimum projection-depth requirements appropriate to the local solar altitude.

iv. Institutional facilities management should incorporate periodic post-occupancy thermal performance evaluation into building maintenance planning, to ensure passive design elements continue to function as intended over time.

v. Further research should extend this assessment through longer-term seasonal monitoring and simulation-based validation, to strengthen the generalisability of findings beyond the sampled buildings.

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