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The Role of Shading Devices in Enhancing Thermal Comfort in Residential Buildings in Bauchi, Nigeria

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***Abstract:** This study investigates the impact of shading devices on occupant thermal comfort in residential buildings within Bauchi Metropolis, Nigeria. Using a survey-based methodology, 120 questionnaires were distributed, with 102 valid responses analysed alongside a checklist assessing building orientation, form, shading, vegetation, and window placement1. Results show that 51% of surveyed buildings had shading devices, and occupants in these buildings reported higher levels of thermal comfort: 29.4% felt neutral and 13.7% felt slightly cool, compared to those in unshaded buildings, where 15.7% felt hot and 10.7% felt warm1. Most respondents (45.1%) wore short-sleeve shirts, reflecting adaptation to the prevailing indoor climate. The findings reveal that buildings with shading devices and optimal orientation (north-south) significantly enhance occupant comfort, reducing reliance on energy-intensive cooling systems. This research quantifies the relationship between specific passive design strategies and user-reported comfort in a tropical Nigerian context, providing practical guidance for architects and policymakers to improve thermal comfort and energy efficiency in residential design by outfitting it with shade structures, as well as landscaping and plants, to limit indirect solar radiation.*

***Keywords:** Thermal comfort, Shading devices, Residential buildings, Passive design, Bauchi Metropolis.*

1. Introduction

Bauchi Metropolis, located in Nigeria's hot, semi-arid climate zone, faces persistent challenges in maintaining thermal comfort within residential buildings (Field survey, 2023). High solar radiation and prolonged hot seasons often result in uncomfortable indoor environments, diminishing occupant well-being and productivity (Mujtaba & Halil, 2017). While passive design strategies such as shading devices are widely recognised for their potential to reduce heat gain and improve comfort, there remains limited empirical evidence specific to Northern Nigerian homes on how architectural shading impacts thermal comfort outcomes (Bello, Allu-Kangkum & Nimlyat, 2021). Most existing studies in Nigeria have focused on general thermal comfort or have relied on outdated or broad global climate data, with few addressing the microclimatic realities and architectural practices unique to Bauchi (Lynas, Houlton, & Perry, 2021). This study addresses this gap by systematically evaluating the effects of shading devices on occupant thermal comfort in residential buildings across Bauchi Metropolis (Field survey, 2023). According to the scientific community's consensus on climate change, the Earth's average temperature has increased from 0.4°C to 0.8°C over the past 100 years, and by the year 2100, it is predicted to rise from 1.4°C to 5.8°C (Mujtaba & Halil, 2017).

As a result of global warming, there may be a rise in sea levels caused by the melting of the polar ice caps, as well as an increase in the frequency and severity of storms and an overheating of hot regions. Thermal comfort, also called human comfort, represents an occupant's satisfaction with the surrounding thermal conditions. It is a subconscious state of mind where an individual feel at ease with the thermal environment, assessed through subjective judgment. Measuring thermal comfort involves considering numerous influencing variables, such as humidity, air velocity, air temperature, metabolic rates, radiant temperature, clothing levels, and occupancy of the same room. These feelings can vary greatly depending on the physiological state of the occupant. The appropriate management of thermal comfort can enhance morale, productivity, health, and safety (Bello, Allu-Kangkum & Nimlyat, 2021). A favourable environment can be created by integrating shading devices into residential structures since thermal comfort can affect people's moods, feelings, and ability to function. The necessity for thermal comfort and ventilation has been met without the need of large energy-consuming machines thanks to the development of mechanical climate control equipment (Hamza, Adamu, Usman, & Usman 2022). Designers should abandon this viewpoint because the gas emissions from this equipment are the main causes of the Ozone layer's thinning. When planning for thermal comfort, nonelectrical or mechanical means should be taken into account more so than inconsiderate designs that include many mechanical temperatures control devices.

In view of the background of the study, the circumstance leading to the cause of this study are that, most residential houses in hot climate suffers from incident solar radiation entering into building spaces through windows and doors openings, occupant of this spaces are not comfortable with the thermal performance of the buildings which decrease their productivity, poor performance and health.

This study aims to evaluate the impact of shading devices on the thermal comfort of occupants in residential buildings in Bauchi State. It investigates the condition of these buildings and their thermal comfort in the hot, sunny climate of Bauchi, Nigeria, with a focus on achieving thermal comfort through the incorporation of shading devices into external building elements.

The objectives of this research are as follows:

1 To assess the significance of thermal comfort on both the building and its occupants.
2 To determine how metabolic rate and clothing affect perceived comfort in tropical climates.

2. Literature review

Achieving thermal comfort in buildings, especially in hot-dry climates like Bauchi, Nigeria, requires a comprehensive understanding of climatic variables and architectural responses. This literature review explores the theoretical foundations, environmental influences, and practical strategies for enhancing indoor thermal environments using solar protection measures.

Understanding Thermal Comfort

Thermal comfort refers to a subjective state where occupants express satisfaction with their surrounding thermal conditions (Parsons, 2002). It significantly influences productivity, health, and well-being (Garcia & Pereira, 2021). Mujtaba and Halil (2017) emphasized that thermal discomfort contributes to symptoms associated with sick building syndrome, including headaches and respiratory issues.

FACTORS INFLUENCING THERMAL COMFORT

Several variables determine thermal comfort, including air temperature, humidity, metabolic rate, clothing insulation, air movement, and radiant temperature. Ishaq and Alibaba (2017) identified metabolic rate as the rate at which chemical energy is converted to heat during physical activity, while clothing insulation regulates heat loss or gain depending on fabric thickness and layering.

Air temperature directly affects occupants' comfort levels and can be manipulated via ventilation strategies (Bean, 2020). Radiant temperature, or the mean temperature of surrounding surfaces, plays a more crucial role in human perception of warmth than air temperature alone. Furthermore, air movement enhances evaporation and provides relief in high humidity environments, which typically hinder sweat evaporation and lead to discomfort (Elraouf, et al., 2022).

IMPORTANCE OF THERMAL COMFORT IN BUILDINGS

Indoor environmental quality, particularly thermal comfort, shapes how occupants perceive and interact with their built environment (Adewale & Kolawole, 2016). Thermal discomfort leads to reduced satisfaction, increased health risks, and diminished performance. According to Chali, Gudina, Eshetu, and Esaya (2019), poor indoor thermal conditions can result in heat strokes, respiratory problems, and dehydration.

STRATEGIES FOR ACHIEVING THERMAL COMFORT

Mujtaba and Halil (2017) outlined that achieving thermal comfort involves integrated design strategies such as site-specific orientation, building massing, passive ventilation, appropriate material selection, and use of shading devices. Designers are encouraged to minimize reliance on mechanical systems due to their environmental implications and promote passive techniques to manage indoor temperatures sustainably.

HEAT TRANSFER AND SOLAR RADIATION

Heat transfer in buildings occurs through conduction, convection, and radiation. Conduction involves heat flow through solid materials (Joseph, Nissa, & Christianly, 2021), convection moves heat through fluids, and radiation emits energy via electromagnetic waves without requiring a medium (Mujtaba & Halil, 2017). Direct solar radiation impacts internal comfort levels, especially when unshaded windows admit excessive heat into indoor spaces.

SOLAR PROTECTION MEASURES

SHADING DEVICES

Solar shading is an effective passive cooling technique. Kumar, Garg, and Kaushik (2005) observed a reduction in indoor temperatures by 2.5°C to 4.5°C using shading devices, which improved further when combined with insulation and controlled air exchange. Windows, being primary heat gain points, benefit immensely from protective shading elements (Olygay, 1957).

Shading approaches include recessed facades, fixed or movable louvers, blinds, and vegetation. These methods mitigate direct, diffuse, and reflected solar radiation, enhancing indoor thermal conditions. Horizontal shading devices outperform vertical ones due to their superior ability to block overhead sunrays (Givoni, 1997).

Overhangs, Louvers, and Awnings

Fixed and movable shading devices affect indoor conditions and aesthetics as shown in Figure 1. Louvers, overhangs, and awnings reduce solar gain while facilitating air movement and preserving views. However, east-west facades pose shading challenges due to low-angle morning and evening sunlight. Interior shading solutions like curtains offer limited effectiveness compared to exterior devices (Mujtaba & Halil, 2017).

Vegetation And Trees

Trees serve as natural shading elements and contribute to air purification. Their foliage lowers surrounding temperatures through evapotranspiration, which helps mitigate urban heat islands (David et al., 2006; Jillian & Jeff, 2021). Leaf size, shape, and density influence shading performance. Deciduous trees, in particular, provide summer shade and allow winter sun, making them ideal for passive design (Mujtaba & Halil, 2017).

Building Orientation, Shape, and Zoning

Orientation and shape significantly influence solar exposure and ventilation. North-south-oriented buildings experience less direct solar gain than east-west-oriented ones, enhancing thermal comfort (Shick, 2009). Studies have shown that rectangular buildings with north-south orientation perform better thermally due to limited sun penetration on the longer sides (Liping et al., 2018; Hachem et al., 2013). Additionally, zoning—grouping spaces according to function and solar exposure—allows designers to place frequently used spaces away from harsh sun angles, enhancing both comfort and energy efficiency (Mirrahimi et al., 2011).

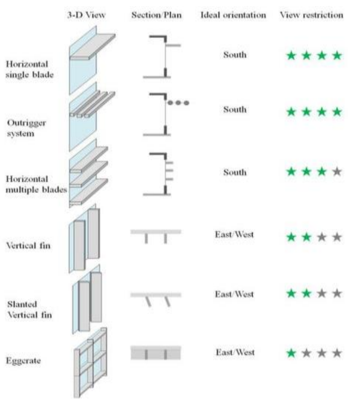

Figure 1: Different types of shading device
Source:(https://www.pinterest.com/dawnbriscoe0607/ shading: devices, 2022)

Summary of Literature Review

The reviewed literature underscores the multidimensional nature of thermal comfort and the critical role of design decisions in achieving it. Shading devices, when thoughtfully integrated with orientation, form, and landscaping strategies, offer significant improvements in thermal comfort and energy performance. Consequently, these strategies should be considered early in the design process to ensure sustainability and occupant well-being.

3. Methodology

The study focused on Bauchi metropolis, particularly three residential neighborhoods: Yelwa Tudu, Millionaires' Quarters, and Gwallameji. These areas represent a mix of building typologies, shading strategies, and orientations. Data Collection

Data were collected using:

1. **Questionnaires**: Distributed to 120 residents (102 valid responses).
2. **Checklists**: Used to assess building orientation, form, shading devices, and window placement.
3. **Visual Documentation**: Plates showing building forms and shading conditions.

Sampling Technique

A simple random sampling technique was used to ensure equal representation of residential typologies.

Analysis Methods

Descriptive statistics were employed to analyze occupant perceptions, shading types, and temperature comfort levels.

The questionnaire's content validity was ensured through expert review and pilot testing, and reliability was confirmed with a Cronbach's alpha above 0.80. This research was conducted in compliance with ethical standards for research involving human participants. Verbal consent was obtained from all participants prior to questionnaire administration. Participation was voluntary, anonymous, and all data were treated with strict confidentiality. Ethical approval was granted by the Department of Architecture, Abubakar Tafawa Balewa University, Bauchi.

Study Area

Bauchi State came into existence on the 3rd February 1976 during the reign of General Murtala Mohammed. The State is part of the North eastern region of Nigeria. Bauchi State was named after the man called Baushe who was a great hunter. The capital of Bauchi State is Bauchi and it is referred to as "Pearl of Tourism". The State is surrounded with States like Kano and Jigawa to the

North, Yobe and Gombe to the East, Kaduna State to the West, Plateau and Taraba State to the South as seen in figure 2. In the year 2006, Bauchi State was recorded to have a total of 4, 676, 46 people according to the National Population Census. The area of the state was put at 49,1119km² (18,965sqmin). Consequently, rains start earlier in the southern part of the state, where rain is heaviest and lasts longer. Here the rains start in April with the highest record amount of 1,300 millimetres (51 in) per annum. In contrast, the northern part of the state receives the rains late, usually around June or July, and records the highest amount of 700 millimetres (28 in) per annum. In the same vein, the weather experienced in the south and the north varies considerably. While it is humidly hot during the early part of the rainy season in the south, the hot, dry and dusty weather lingers up north.

Figure 2: Map of Nigeria showing Bauchi State
Source: nationsonline.org (2022)

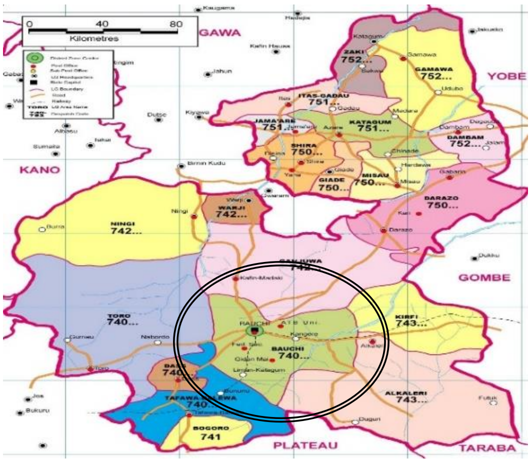

Figure 3: Map of Bauchi State (Bauchi metropolis is encircled)
Source: nigeriazipcodes.com (2021)

The study area is the residential buildings within Bauchi metropolis, Yelwa tudu, Millionials quarters and Gwallameji. These buildings comprised those with shading devices and those without shading devices, buildings with different shapes, different orientation pattern and buildings with landscape and those without landscape as seen figure 4 and 5. A total number of one hundred and twenty questionnaires were distributed randomly within the study area, Yelwa tudu, Millionial quarters, and Gwallameji, Bauchi state, one hundred and two were retrieved successfully, each questionnaire is attached to a checklist.

Figure 4: Buildings with vegetation and trees
Source: Field Work 2023

Figure 5: Buildings with eave overhang
Source: Field Work 2023

4. Results and Discussion

Demographics
Most respondents (60.8%) were male; 90.2% had tertiary education, and 64.7% were single. The dominant occupation was student (43.1%).

Thermal Comfort Perceptions
1. 29.4% of respondents reported "neutral" thermal comfort.
2. Discomfort peaked during afternoon hours (44%).
3. Primary sources of discomfort: excessive heat (89%) and solar gain (11%).

Influence of Shading Devices
1. 51% of buildings had shading devices.
2. Vegetation was the most used (54%), followed by egg crate devices (27%).
3. Buildings with shading devices reported better thermal satisfaction than those without.

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Building Orientation and Shape

1. 65.6% of buildings were rectangular.
2. 56% oriented north–south had less heat ingress.
3. East–west orientations without shading showed higher discomfort levels.

How important is thermal comfort in relation to both the building and its occupants?

Occupants responds on thermal comfort. Table 1, responded to their thermal comfort as hot, 10.7 responded warm, 21.6 responded slightly warm, 29.4 responded neutral, 13.7 responded slightly cool, 5.9 responded cool while 0% respondents cold.

Table 1: Occupants responds on thermal comfort

Thermal	Frequency	Percentage (%)
Hot	16	15.7
Warm	14	10.7
Slightly warm	22	21.6
Neutral	30	29.4
Slightly cool	14	13.7
Cool	6	5.9
Cold	0	0
Total	102	100

Source: Field survey (2023)

This survey shows that most of the respondents feel neutral on their thermal comfort.

On the question asked as to what extent does metabolic rate and clothing insulation influence thermal comfort? Clothing of the respondents indicate from table 2 that 45.1% of the respondents were wearing short sleeve shirt at the top, 9.8% were wearing long sleeve shirt, while 0% were wearing sweater vest, suit vest, long sleeve sweater, long sleeve sweatshirt, 29.4% were wearing t-shirt, 15.7% were wearing thermal underwear top, and at the bottom, 29.4% were wearing trousers, 21.5% were wearing knee-length skirt, 29.4% were wearing walking shorts, 2.0% were wearing overalls, 9.8% were wearing jeans, 0% were wearing athletic wear pants, 6.0% were wearing ankle-length skirt, and 3.9% were wearing thermal under wear bottom. This survey shows that most of the respondents were wearing short sleeve shirt at the top and trouser/walking short at the bottom.

Orientation of Building

From the table below, it shows that 56.0% of the buildings are facing the north and south direction while 44.0% are facing the east and west direction.

Table 2: Orientation of building (Rectangle, L-shape and U-shape)

Orientation	Frequency	Percentage
North/south	41	56
East/west	32	44
Total	73	100

This survey shows that most of the rectangular, U-shape, and L-shape buildings are facing the north and south direction.

Table 4: Respondents' Thermal Satisfaction by Shading Device

Shading Device Type	No. of Respondents	Satisfaction (%)
Vegetation	28	78.6
Egg Crate	14	64.3
Vertical	2	50.0
None	50	28.0

Discussion

Based on the analysis from the study, it is clear that most of the buildings whose windows are facing the east and west direction and have no shading devices, most often suffers from hot and warm thermal comfort and the occupants are not satisfied with the temperature in the house due to the hot temperature in the afternoon. Most of the occupants use to wear shorts sleeves shirt and trousers in order to adjust to the temperature in their houses

Also, data collected from the checklist shows that most of the rectangular buildings whose windows are facing the east and west direction and have shading devices, their thermal comfort is seen to be neutral and cool hence the occupants are satisfied with the temperature in their houses. Buildings with longer side facing the north and south direction even without shading devices the temperature also is seen to be neutral because there is no direct solar radiation in to the interior spaces of the building and the occupants are satisfied with the temperature in the house.

Summary of Findings

1. Thermal comfort is significantly improved through the integration of shading devices.
2. Vegetation and north–south orientation proved most effective.
3. Occupants adjust clothing and activities to cope with discomfort, indicating a need for passive design prioritization.

Recommendations

1. **Design Preliminaries**: Architects should prioritize site-specific analysis, including solar path and microclimate conditions.
2. **Policy Framework**: Building codes should enforce shading integration, especially in hot climates.
3. **Use of Vegetation**: Urban landscaping should be promoted as a low-cost shading solution.

4. **Orientation Awareness**: Educating developers on building orientation can enhance design outcomes.
5. **Academic Integration**: Architecture schools should mandate shading in student design proposals.

Conclusion

This study confirms the critical role shading devices play in ensuring thermal comfort in residential buildings in Bauchi. Passive solutions such as vegetation, proper orientation, and shading structures like overhangs and egg crates offer tangible benefits. Incorporating these strategies during the design phase promotes sustainability, energy efficiency, and occupant well-being.

Future Research

Future studies should conduct post-occupancy evaluations across different seasons to assess year-round comfort. Simulation-based analyses and broader sampling across diverse Nigerian climates are also recommended to validate and expand on these findings.

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