

Implication of Shading Passive Strategies in Buildings of Hot and Humid Climates for Energy Optimization: Lessons from Vernacular Dwellings in Nigeria

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Abstract

Residential buildings consume approximately 30% to 40% of total primary energy, representing a significant share of the world's energy consumption. The contemporary designs of residential high-rise buildings in Nigeria borrow from different climates and adapt to Nigeria's hot and humid climate. Shading is an effective strategy for reducing solar heat gain and improving cooling conditions in hot and humid climates. This study tries to explore the most effective and most adaptable shading elements in the study area to be implicit in the contemporary design of high-rise residences. This study has a particular emphasis on shading techniques; hence, it will examine and present existing literature on shading devices and strategies. The aim of this research is to minimize energy consumption in residential buildings in Nigeria. Therefore, the research investigates the most effective shading strategies in the vernacular buildings that can be utilized as design criteria in future buildings. The findings led to identifying the effective and adaptable shading strategies found in vernacular architecture, which can be utilized in contemporary high-rise residential buildings in Nigeria for energy optimization. Finally, the research suggests guidelines to support architects in reducing energy usage in high-rise residential buildings in Nigeria.

Keywords: Shading Strategies; Building Energy Optimization; Vernacular Architecture; Hot and humid climate; Nigeria.

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1. Introduction

The emergence of the Industrial Revolution in the 1900s has been marked as an era-defining period in human history. On one hand, it has resulted in both economic and social progressions, and on the other, it has proven detrimental as a major catalyst for greenhouse emissions and climate change. Due to less options for outdoor activity due to high temperatures, chronic diseases may become more prevalent (Kjellstrom et al., 2010; Deilami et al., 2020). The Australian Medical Association (Strengers et al., 2014) refers to heat as a “silent killer”.

According to Adamu et al. (2020), the International Energy Agency (IEA, 2002), residential structures utilise between 30% and 40% of all primary energy, using a substantial proportion of the world's energy. In Nigeria,

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the residential sector uses the most energy, with around 65% of total consumption (Oyedepo, 2012; Adamu et al., 2020).

Amasyali, et al. (2018), Oliveti, et al. (2011), and Krarti, et al. (2017), were cited by Mohammed, et al. (2022) stating that recently, 40% to 50% of energy in the form of electricity consumed through buildings, while 30% is consumed through cooling or heating, ventilation, and air conditioning systems (HVAC). As of mid-November, 2022, The World Health Organization (WHO) informed that the global population is expected to increase by about 25% of the current population by 2050. This would constitute a 50% increased urban housing by 2050, and 70% by 2080. The repercussion for an increased population and urbanization is an increased energy demand for HVAC by buildings (Guo, et al., 2021). In response, there has been a growing interest in sustainable building design and energy optimization strategies for reducing energy consumption and mitigating the impact of climate change.

Multi-story residential buildings within hot and humid climates are exposed to excessive solar heat gain and high energy consumption. Mohammed, et al. (2022) stated that, there is a large stream of strategies that when adequately employed, would have positive yields in terms of reducing buildings' energy demands. Amidst these strategies for energy optimization, Alhuwayil, et al. (2019) stated that passive design techniques have been known to yield viable results. To employ these strategies, the building forms, the building envelop, orientation, shading, thermal insulation, natural ventilation, daylighting, building materials, microclimate and fabric need to be taken into account right from the conceptual design phase (Alhuwayil, et al., 2019).

This research is more inclined toward shading strategies; therefore, existing works on shading devices and strategies will be reviewed and put forth.

Shading devices, such as louvers, fins, and screens, have been pointed out as an effective strategy for reducing solar heat gain, and cooling loads upon the building whilst enhancing natural ventilation. Shading devices are elements known to be utilized on buildings both internal and external for achieving thermal, as well as visual comfort whilst optimizing energy demand by the building (Alelwani, et al., 2019).

It has been found that interior spaces in tree-shaded structures are frequently cooler than those in unshaded ones, with lower rates and volumes of heat transmission, cooling energy demand, and cooling energy expenditure (Guerra Santin et al., 2009; Morakinyo et al., 2016). Ishaq and Alibaba (2017) cited that Kumar et al. (2005) investigated the efficiency of solar passive cooling methods including solar shading and building component insulation. The study found that integrating solar shading devices resulted in a 2.5 to 4.5 °C drop in interior temperature. The outcome was further altered by the employment of insulating material and a controlled air exchange rate, which revealed a more notable decrease of the indoor temperature of 4.4 °C to 6.8 °C.

However, the effectiveness of shading devices depends on design strategies and materials selection. This study aims to analyse the impacts of shading on energy optimization required for HVAC, for a tall residential structure in climates with high temperatures and high humidity. Acknowledged, there are other passive shading variables like material, orientation, and form, but this study was focused on shading strategies like shading devices, natural features, and roof overhangs. See Figure '1'.

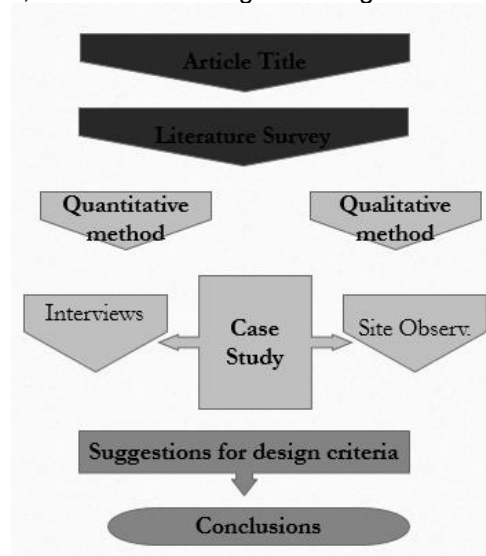


Figure 1. Structure of the Study

2. Literature Review

2.1 Vernacular Architecture

Vernacular is a word derivative of the Latin term "Vernaculus", which depicts domestic (Oliver, 1997). Although there are links between the two, there are distinct variations between vernacular architecture, and it is vital not to get it mixed up. Supic (1982) stated, the degree of urbanity is what distinguishes the "vernacular" style of architecture, which is more or less a synonym for vernacular, archaic, rustic, peasant, impromptu, anonymous, indigenous, or without architects. It is Unassuming, straightforward, indigenous, vernacular buildings created from local resources and utilising tried-and-true forms and types (Arboleda, 2006).

Vernacular architecture is a human construction that is derived from the intertwining environmental, social, political, material, economic, and other aspects in relationship (Asquith, and Vellinga, 2006). Important 19th and 20th century architects, such as F. L. Wright, R. Neutra, W. Gropius, H. Meyer, Mies van der Rohe, Le Corbusier, and Moholy Nagy, paid homage to vernacular architecture and saw it as the origin of new architectural theories because of how simply it expresses its contents (Supic, 1982).

Vernacular architecture is a branch of architecture that takes into account local necessities, building materials, and traditions (Arboleda, 2006). Brunskill (1972) defined vernacular architecture as the function of the building would be the main factor, and aesthetic considerations, though present to some extent, would be relatively minimal. Vernacular architecture is defined as buildings created by a layperson without design expertise will be guided by a set of norms that have developed in his environment, with little regard for what may be fashionable.

Vernacular architecture changes with time to reflect the technological, environmental, cultural, economic, and historical epoch. Whereas mostly difficult to come to terms with the regulatory and mostly known requirements of the aforementioned five aspects, this type of architecture remains vital to architecture and design, especially in the local levels (Arboleda, 2006).

Oliver (1997) describes that, every form of vernacular architecture is built to cater for the requirements, bring forth values, economies, and way of living in terms of culture that forms them. In his book, *Dwellings*, Oliver declares that, it is debatable if "popular architecture," which is created by professionals or commercial builders for general public use, fits within the definition of "vernacular". Oliver goes further by defining vernacular architecture is defined as being built by and for the people, yet not for them.

Noble(2009) noted that although qualified professionals, such as those who have completed an apprenticeship, can construct vernacular architecture, it is still the style used by the average person and still uses regional, traditional styles and materials.

Nigeria has a rich tradition of vernacular architecture, which has evolved over centuries to address the challenges of the country's hot and humid climate. Vernacular dwellings in Nigeria have incorporated passive shading strategies to optimize energy use and improve comfort levels for occupants.

In the past, several vernacular strategies are built with respect to the domestic culture, climate, and location (Aziz, and Shawket, 2011). There are several factors to be considered for methods or strategy selections for buildings: economic, climatic, social demands, builders' skill level, and availability of the local materials. With these in mind, the climate is considered one of the most vital aspects that is influential to vernacular developments. From the beginning of civilization, people have been known to customize their homes with respect to their subjective climatic conditions, hence the use of climate-responsive elements and materials for construction (Oktay, 2006).

Building shapes, materials, and orientation are affected by climatic factors such as humidity, air pressure, solar radiation, wind direction, temperature, and precipitation (Yaldiz, 2009).

Rapoport (1969) differentiates between primitive, folk, and vernacular architecture. According to anthropologists, primitive architecture refers to constructed forms that were created by primitive people. Folk tradition is described by Rapoport (1969) as the direct and unashamed translation of a culture's requirements, ideals, goals, dreams, and passions into physical form. The following is a collection of Rapoport's definition of vernacular architecture:

1. *Absence of theoretical aspirations;*
2. *Adopted to the location and microclimate;*
3. *Being respectful of others, their homes, and the environment as a whole;*
4. *Limited by an idiom and having variations within a predetermined order.*

Hence Nigeria majorly falls within zones with hot and humid climates, the next part is affiliated with its characteristics and effects on the vernacular built environment.

2.2 Hot and Humid Climatic Characteristics

Here, generic works of literature on the exemplary characteristics of hot and humid climates will be put forth for review. Random zones were selected and reviewed solely based on their hot and humid climatic characteristics.

According to Makaremi et al. (2012), Malaysia experiences gloomy skies, mild breezes, lengthy stretches of sunshine, high relative humidity, and year-round high temperatures. Daily air temperatures range from a low of 24 °C to a high of 38 °C; the minimum temperature is typically observed at night. Malaysia has high relative humidity, with mean monthly values range from 70% to 90% throughout the year and from location to location and month to month. Nevertheless, according to Dahlan et al. (2008), the mean daily humidity can range from 42% to 94%.

Colombia has a typical savannah climate (Villadiego et al., 2014). According to Höppe (1999), the mean annual relative humidity is 80%, the mean annual temperature is 28 degrees Celsius, the maximum temperature variation is 10 degrees Celsius, and the average annual precipitation is 900 mm. In the city, there are just two seasons: the dry and the wet ones (Hoppe, 1999). From December through March, there are no rainy days and trade breezes, as well as plenty of sunshine and beautiful skies. The trade winds have an average wind speed of 4.0 m/s and originate in the northeast (Hoppe, 1999). He continues by saying that when the rainy season is present, high relative humidity, a lot of rain, and storms are typical throughout the rest of the year.

Regions like Australia, central Africa, North America, and Asia having hot and humid climates are located all over the world. See Figure '2'.

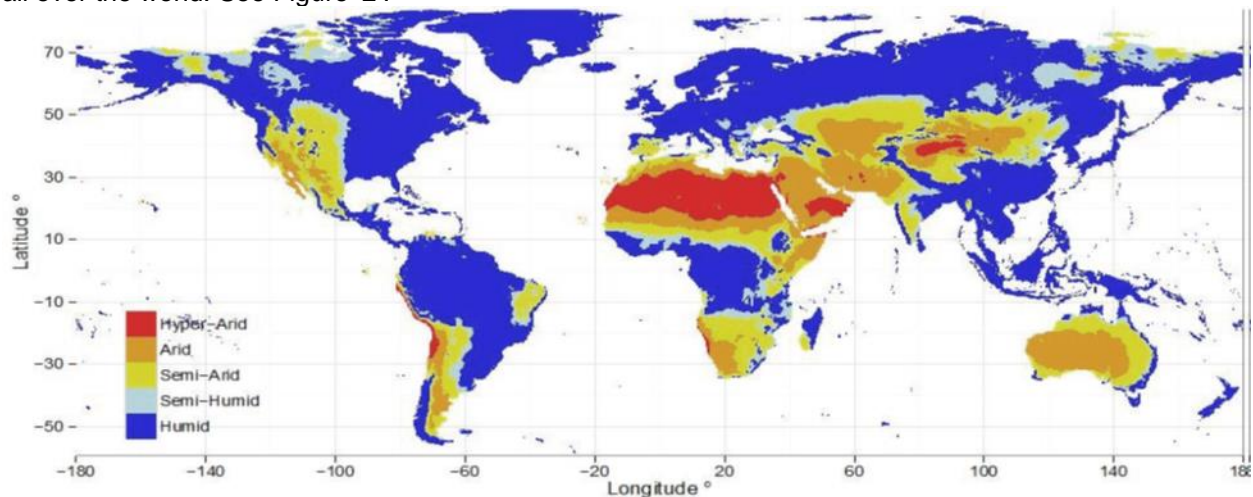


Figure 2. Map of climatic zone distribution (CGIAR-CSI, 2019).

2.3 Vernacular Architecture in Hot and Humid Climates

Generally, the major climatic elements associated with hot and humid climatic zones are solar heat and humidity. The building styles and techniques used by local dwellings in a particular region aim to mitigate the effects of excessive solar heat and humidity.

This section reveals the domestic architectural practice within hot and humid characteristics. In hot and humid climates, vernacular architecture plays a crucial part in the development of buildings that can withstand the difficulties posed by climatic circumstances (Oliver, 1997). Culture, indigenous, material (local), and geography are all important terms for defining Vernacular architecture (Srivastava and Das, 2023). For instance, in Southeast Asia, buildings are often constructed using bamboo, thatch, and other natural materials that are well-suited to reduce and withstand the high humidity and heavy rainfalls (Asquith, and Vellinga, 2006; Edson and Dean, 2006).

These materials are also adequately lightweight and they are good for providing thermal comfort for the indoor space. See Figure '3'.



Figure 3. Tharu house with wide roof overhang and shaded veranda in Chitwan (Bodach, & Hamhaber, 2014).

The goal of Vernacular architecture in hot and humid climates is essentially inclined towards cooling. For this reason, passive cooling strategies are the most devised. These strategies are: high ceilings; shaded openings; and natural ventilation through cross-ventilation (Beccali et al., 2018). For instance, in Kerala, India, Vernacular houses are often designed with open courtyards which allow the breeze to flow through the building, while the high-pitched roofs provide shade and protection from solar radiation (Joseph et al., 2020).

In addition to passive cooling strategies, many vernacular buildings of hot and humid climates supplement water elements such as fountains, pools, and ponds. These elements provide a source of cooling, and humidity control, and also serve a cultural and aesthetic purpose (Narendra, and Daketi, 2016). Furthermore, vernacular architecture in hot and humid climates is characterized by the use of natural, locally available materials, passive cooling which falls under passive design strategies which leads to the next aspect of the literature survey. But prior to that, it is important to understand through reviews, passive buildings as energy efficient buildings.

2.4 Passive Buildings as Energy Efficient Buildings

An energy-efficient building is one whose energy demand is at or below 50% of the energy demand of a typical building while still providing for the comfort of its occupants. When passive building techniques are used in accordance with the climate, a home is considered to be passive. Buildings with acceptable thermal comfort for the residents and low energy usage are known as passive houses. The Passive House not only uses certain construction methods but also suggests a number of performance benchmarks. The architect can also choose the architectural style and building materials based on the local climate and the building's necessary energy requirements (Fesharaki, 2018).

The flexibility and ability of passive buildings to adopt to various climatic conditions is a benefit. Depending on the climate in which the building is located, different passive house concepts apply to different buildings. As will be discussed in the section on passive design techniques for hot and humid climates later in this chapter, the emphasis in hot locations, for example, tends to be on passive cooling strategies, such as ventilation systems, shading, and control of heat gain.

2.5 Passive Design Strategies

Passive design strategies imply to the use of natural energy flows and materials to create thermal, visual and acoustic comfort whilst ensuring that energy is optimized within buildings. Akande (2010) states that the ideal environment for human habitation is maintained in well-designed passive structures while the expense of energy is kept to a minimum. The goals of passive buildings are to raise occupant comfort levels and cut down on energy use for heating, cooling, and lighting (such as electricity and natural gas). Because conventional energy sources are limited in terms of their affordability and availability, passive building design is crucial in hot climates (Hyde, 2000; Akande, 2010). Passive solutions aim to develop more energy-efficient architectural components (such as building envelopes and roofs) in order to reduce the demand for active solutions (Sadineni et al., 2011; Sun et al., 2018).

Passive design strategies can also present challenges, mainly which is ensuring that the design is appropriate for the local climate and environment. The uses of passive solutions, such as daylighting and natural ventilation, are constrained by their sensitivity to climatic and external factors (Al-Obaidi et al., 2014; Chen et al., 2017; Gamage et al., 2017; Khambadkone and Jain, 2017; Sun et al., 2018). Sun et al., 2018 acknowledged the research (Abro, 1994; Jafari & Poshtiri, 2017), passive solutions typically have minimal additional capital investment costs compared to the possible benefit in energy savings. Financial risk and

uncertainty is one of the key mitigating factors for upgrading older buildings (Miller and Buys, 2008). This literature section focuses on passive design techniques for vernacular homes in hot and humid areas in order to promote energy efficiency and thermal comfort.

2.6 Passive Design Strategies in Vernacular buildings of Hot and Humid Climates

Buildings in hot and humid areas must provide thermal comfort while consuming less energy. In these areas, passive design techniques have been widely used to enhance interior thermal conditions and decrease the need for mechanical cooling systems. Vernacular buildings on the other hand, provide a rich source of effective passive design strategies. This part will reveal some of the most effective passive design strategies in vernacular buildings of hot and humid climates.

2.6.1. Natural Ventilation

This is an important strategy used by vernacular buildings within hot and humid climates. It improves indoor quality through allowing the less dense hot air out while allowing the denser cool air into the building. It's been stated that vernacular buildings in hot and humid climates incorporate natural ventilation through the use of courtyards, perforated walls, and open spaces (Gupta, 2017).

These elements promote thermal comfort and reduce energy consumption by promoting airflow through the building.

2.6.2. Thermal Mass

This is an essential passive design strategy ideal for hot and humid climates due to the high temperature and solar radiation during summers. Thermal mass forms part of the passive design strategy that constitutes the use of materials that have a high heat capacity to absorb and retain heat. Local materials use is essential for effective indoor thermal comfort. Especially materials with thermal resistance like mud bricks, and stone (Chandel et al., 2016). Because rammed earth construction uses less embodied and operational energy, there are significant energy savings (Chandel et al., 2016). See Figure '4'.



Stone construction



Adobe construction



Rammed earth construction

Figure 4. Building materials selection based on local sources and thermal potential in hot and humid climates (Pinterest, 2023)

These materials absorb and store heat during the day and releases it at night, by such, reducing indoor temperature fluctuations and promoting thermal comfort.

2.6.3. Roof Insulation

A passive design technique called roof insulation uses insulation materials to stop heat transfer through the roof. Using materials like straw, clay tiles, and coconut leaves, vernacular buildings in hot, humid conditions can accomplish roof insulation (Chandel et al., 2016). These materials provide effective insulation and reduce heat gain in buildings, improving thermal comfort.

2.6.4. Courtyard

Courtyards also referred to as patio have been an integral part of vernacular dwellings in hot and humid climates for centuries. They offer a range of passive design strategies that aid in mitigating heat gain and improving thermal comfort. In vernacular buildings in hot and humid climates, central courtyards are considered a fundamental element. Li et al. (2018) points out that courtyards when properly designed, can improve thermal comfort and reduce heat gain in living spaces by providing natural ventilation, daylight, and shading.

Courtyards, if appropriately designed, can be an effective passive cooling strategy in hot and humid climates. It was found that when vegetation is instilled within courtyards thus creates a microclimate that lowers the temperature of the surrounding area (Sun et al., 2021). They provide the opportunity for natural ventilation and facilitate air circulation from the courtyard into the building. They also provide a shading effect by reducing direct solar radiation on the building walls, thus reducing heat gain.

Solutions for patio design can be adapted to the unique requirements and difficulties in various areas. Particularly in hot and humid climates, protection from the sun, hot winds, and high humidity should be at the forefront of the design. The design should also take into account the local culture, lifestyle, and architectural history.

2.6.5. Shading

Shading is another important passive design strategy in hot and humid climates. It reduces solar radiation and prevents heat gain in buildings. Shading of buildings can be achieved in a variety of ways, including plants (trees), shading devices such as overhangs, or other architectural elements. It is strongly related to the size, orientation and shading of buildings (Brawm and Dekay, 2001). Vernacular buildings in hot and humid climates have overhangs, louvers and shading devices (Chandel et al., 2016). These devices block direct solar radiation and reduce heat gain in buildings, improving indoor thermal comfort.

As the title states, this paper focus on passive shading strategies for hot and humid climates with reference to vernacular dwellings. That leads to the next literature to be reviewed.

2.7 Passive Shading Strategies

There are various passive design strategies associated energy optimization and comfort, but this research opts solely for passive shading strategies because it is the easiest passive design strategy that can be retrofitted upon both existing and proposed building designs. It is also easily adoptable by households of all strata as its low-cost option. These involve the use of natural elements such as shading devices, trees, and overhangs to shield from the direct solar rays and thus reduce heat gain in buildings. Passive shading strategies play a vital role in reducing heat gain and promoting energy efficiency in buildings. Overhangs, trees, external shading devices, and internal shading devices are all popular passive shading strategies that provide shade and regulate the quantity of direct solar radiation entering the building. The layout of the building, shading devices, envelop thermo physics, fenestration, infiltration and airtightness are only a few examples of passive design solutions (Rodriguez-Ubinas et al., 2014; Liu et al., 2020). At an early design stage, architects may use suitable passive designs to achieve a high building performance. Researchers from throughout the world evaluated several passive adaptation strategies to mitigate the effects of climate change (Liu et al., 2020). In this literature review, focused on the effectiveness of these passive shading strategies in energy conservation and improving indoor thermal comfort.

2.7.1. External Shading Devices

External shading devices are installed on the exterior part of building envelopes, this is to prevent direct sun rays and also to reduce heat gain. The use of exterior shading devices on building facades to reduce solar radiation is a crucial component of passive design. Although studies have demonstrated the advantages of exterior shade devices, many of them are just built for cosmetic reasons, neglecting their significant ability to minimise solar radiation and glare (Shahdan et al., 2018). Popular passive shading techniques that prevent direct sunlight from entering the building include external shading devices like louvres, vertical fins, and shading screens. See Figure '5 (a)'.

In tropical and subtropical areas, where substantial volumes of direct sunlight enter buildings, they are frequently used. According to studies, devices that provide exterior shading could cut the indoor cooling load by 30% and be made of either living plants or building materials (Balaras et al., 2000; Shahdan et al., 2018). To reduce cooling loads on buildings, external shading devices are more effective than high performance glazing (Balaras et al., 2000). The size, shape, and position of external shading device, are telling factors on its effectiveness (Cho and Kim, 2014).

2.7.2. *Overhangs*

Overhangs are horizontal extensions of a building's outside wall that provide shading. These projections can be made to obscure the sun's rays during the summer while letting them pass through during the winter. The appropriate use of overhangs would result in a decrease in the yearly energy consumption of buildings (Ebrahimpour and Maerefat, 2011). They are one of the most vital strategies for passive solar building designs (Stefanović, 2013).

Studies have shown that overhangs can significantly reduce heat gain and improve indoor thermal comfort. Ebrahimpour and Maerefat (2011) in their study, cited that Bojic (2006) discovered that the use of overhangs might cut electricity consumption by up to 5.3% using the software EnergyPlus™. Using the same programme, Bojic discovered that adding side fins to a structure with overhangs might cut power use by up to 1.4%, with the biggest savings occurring at windows with out of-core side fins that face either north or south (in the west wing). Similarly, Krarti (2021) reported that buildings with overhangs had lower internal temperatures and reduced energy consumption for cooling compared to buildings without overhangs.

2.7.3. *Natural Strategies (Trees)*

Trees are another passive shading strategy that can reduce heat gain and improve indoor thermal comfort. Trees provide shade and help reduce direct solar radiation on the building. According to Hashemi and Khatami. (2017), the hottest times of the year are when shading techniques work best, cutting the risk of excessive overheating by up to 52%. according to a study in the context of Uganda, they cited UNDP (2015), revealing that Uganda has considerably very low access to electricity (18.2%) and thus, the primary form of ventilation and cooling used in the majority of buildings is natural ventilation (Hashemi and Khatami, 2017). Trees also have other environmental benefits, such as improving thermal comfort, through improving air quality, reducing noise pollution and promoting biodiversity (Wood and Salib, 2013). Planting trees improves the landscape, creates shading, and gives residents access to oxygen (Kaita and Alibaba, 2016).

2.7.4. *Internal Shading Devices*

Internal shading devices such as curtains, blinds and shades can also provide effective shading and improve indoor thermal comfort. (Heidari et al., 2021) interior shading devices include venetian blinds and roll screens. These devices are relatively inexpensive and easy to install and can be adjusted according to the amount of sunlight. Internal shading is more flexible, cheaper and easier to repair (Ye et al., 2016). In their study, Kaita and Alibaba (2016) found that indoor shading devices can create a sense of privacy. There several factors to consider when installing internal shading devices. Kaita and Alibaba (2016) found that the sun path, shading type and its category in terms of fixed, movable or adjustable should be amongst variables to consider when installing internal shading devise. Hong et al. (2018) proffered that, according to how they operate, shading devices can be divided into three categories: fixed type, manual type, and movable type.

2.8 Passive Shading Strategies in Vernacular dwellings of Hot and Humid Climates

Passive shading strategies are critical for maintaining comfortable indoor conditions in hot and humid climates. Vernacular dwellings have long incorporated these strategies to mitigate the effects of solar radiation on building envelopes and to achieve thermal comfort.

2.8.1. *Overhangs for Hot and Humid Climates*

One of the oldest and most widespread passive shading strategies is the use of overhanging roofs. The humid zones require shade externally by adopting the use of large overhangs and other devices to render protection to the building (Fry and Drew, 1964). See fig. 5 (b) for a sample of roof overhangs.

The overhangs effectively shield windows and walls from direct sunlight, lowering indoor temperatures and minimising glare. In regions with high rainfall, vernacular dwellings use a high thatched roof with eaves overhangs to protect walls and openings (Srivastava and Das, 2023). This tactic is also used in contemporary sustainable architecture, such as Passive Solar Radiation, where a building is oriented so that its longest side faces south, with the majority of its window openings along it and overhangs covering the openings to keep the sun from radiating through (Idris, 2016). In Nigeria, it's advised to have overhanging roofs by at least 1.0m to reduce or mitigate the impacts of both rain and sun upon the walls and openings (Arum and Falayi, 2012).

2.8.2 Shading Screen

Another passive shading strategy is the use of shading devices such as shutters, blinds and screens. Compared to fixed overhangs, shading devices offer more flexibility in controlling the amount of sunlight that enters the building. Like most parts of Nigeria, Lahore, Pakistan is also known to have a hot and humid climate. Batool (2014) found that the contemporary commercial dwellings in the Interior roller shades, blinds, and screens are frequently used in the Middle East to reduce heat gain but do not block sunlight. When compared to external shading devices, they increase the building energy (Moeck et al., 2013; Batool, 2014). According to earlier research (Alzoubi and Al-Zoubi 2010; Lau et al 2016; Elzeyadi and Batool, 2017), the amount of energy savings achieved varies depending on the type of shading, the geometry, and the climatic fluctuations. Modern structures constructed in hot climates frequently draw design cues from conventional screens like the Jali and Mashrabiya (Elzeyadi and Batool, 2017). Jali or Jaali (Indian spelling) screen is a latticework is an openwork framework made of strips of several types of construction material arranged in a crisscrossing pattern (Prasad et al., 2022). The amount of time spent indoors within the comfort range in Qatar's capital city of Doha improved dramatically thanks to a well-designed external shade, the authors claim, increasing it by anywhere between 13.3% and 50% on average per year (Elzeyadi and Batool, 2017).

There are distinct types of Solar/shading screens mostly categorized by width/depth, materials composition, and geometry. The geometric patterns found in Jali screens can be boiled down to a collection of geometric forms (Sourdel-Thomine, 1966). See figure '5 (c)'. Hexagons are the most common shape for the Jali screens (Sourdel-Thomine, 1966).

Maintaining privacy and security while providing a building's interior with air and lighting is one of the key goals of Jali screens. It is frequently utilised on buildings' upper floors, where it helps control temperature and provide a cozy living space. Elzeyadi & Batool (2017) reported that in other studies (Raymond and Hattice, 2008) lighter screen systems consisting of external cables provide reduced cooling loads while maintaining privacy.

2.8.3. Natural Elements

Natural elements such as trees and water can also be used as passive shading strategies. Trees provide natural shading by blocking solar radiation while promoting natural ventilation and evaporative cooling. See Figure '5 (d)'.

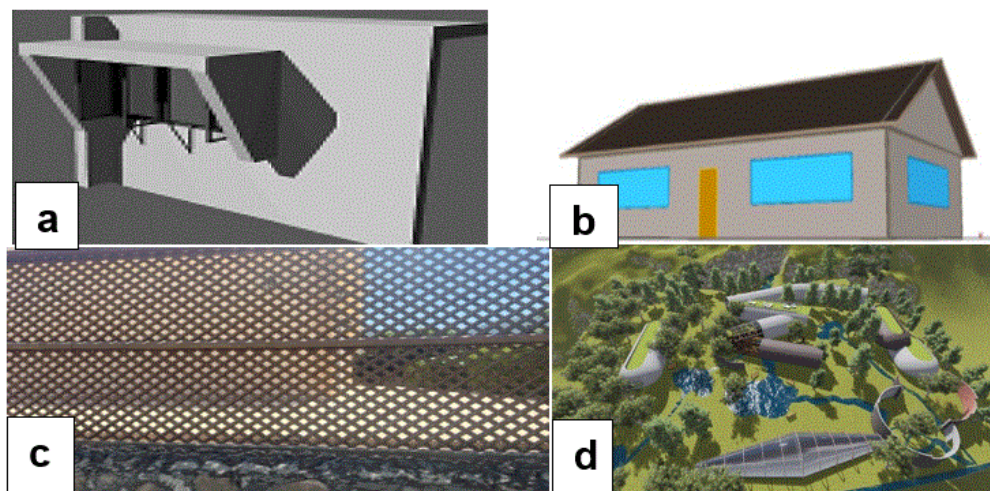


Figure 5. (a) External shading devices (Wong, & Istiadji 2004);
(b) Shows overhangs (Krtati, 2021);
(c) Showing a jali screen (Authors);
(d) Revealing the application of trees.

It is known that, depending on the local climatic and environmental conditions, locations shaded by trees can be up to 5.6 °C colder than areas that aren't (Sanusi et al., 2017; Deilami et al., 2020).

According to numerous studies (Lynn et al., 2009; Rosenfeld et al., 1998; Rosenzweig et al., 2009; Zhou and Shepherd, 2010; Coutts et al., 2013) and studies on climate change adaptation (Gill et al., 2007; Coutts et al., 2013), adding vegetation to urban areas has been proven to lower urban temperatures. Less attention is placed on the impact that water has on urban climates through irrigation and the upkeep of urban

vegetation (Coutts et al., 2013). Water features, such as ponds or fountains, can also cool the surrounding air through evaporation, providing a natural source of cooling. Coutts et al., (2013) also cited Larson et al., (2009) that drought, water restrictions, and xeric gardens, together with the diminished health of urban plants, may all worsen urban warming and energy needs.

3. Methodology

3.1 Study area

The field study was conducted in the vernacular dwellings of Nigeria. The southern section of Nigeria, which is located at latitude 9°04' 39.90" N and longitude 8°40' 38.84" E, experiences a tropical monsoon climate with year-round high temperatures, high humidity, and copious rainfall. The average daily maximum temperature is 31.6 °C, and the average daily lowest temperature is 13.1 °C. According to Akande (2010), the mean relative humidity is highest in August (66.5%) and lowest in February (16.5%). In the extreme north, rainfall amounts on average hover around 700 mm annually, according to Akande (2010). Between September and May is the dry season, while between May and September is the rainy season. See Figure '6'.

3.2 Data collection

In a bid to bridge the gaps between philosophical assumptions/questions and validations, a mixed-method, through quantitative and qualitative approaches based on objective indicators, and subjective indicators. Subjective indicators for data collection included interviews and surveys with professionals like, architects, engineers and academicians.

Objective indicators for data collection were be guided through systematic literature review with recommended best practices on the research topic will be acquired from articles from peer-reviewed journals and academically certified literatures.

The case study methodology was conducted based the most frequently or predominant passive shading strategies adopted by vernacular dwellings in a hot and humid climate of Nigeria.

The data (most prominent shading strategies found to be adopted through case studies within the vernacular dwellings, we administered a Likert scale semi-structured interviews to fifteen (15) professionals in the form of architects, engineers and academicians to collect, subjectively, the best shading strategies for multi-story contemporary buildings. It is crucial to mention, in qualitative research, the sample sizes commonly encountered typically fall within the range of 20 to 60, as highlighted by Bekele and Ago (2022). However, Guest et al. (2006) and Muhy Al-Din et al. (2023) propose a more conservative approach, suggesting that a modest number of 12 to 16 interviews is adequate for a qualitative research project. Nevertheless, Likert's scale as a statistical tool has been applied to collect qualitative and quantitative data and gives quantitative results to determine the optimum results derived for energy optimization from different variables.

A paradigm by the name one-way analysis of variance (ANOVA) was used to compare the mean results from the conducted interviews allocated to the professionals as earlier mentioned. The formula for one-way ANOVA involves calculating the F-statistic, which is used to assess whether there are significant differences among the means of the group of professionals.

3.2.1. Systematic review of the most effective passive shading strategies for hot and humid climates

The most effective passive shading strategies for buildings in hot and humid climates with regards to the vernacular practices were reviewed. Based on literatures from past researchers, the most prominent and effective passive shading strategies are:

Studies have shown that external shade devices, which can be built of either living plants or building materials (Balaras et al., 2000; Shahdan et al., 2018), can lower the indoor cooling demand by 30%. To reduce cooling loads on buildings, external shading devices are more effective than high performance glazing (Balaras et al., 2000). (Shahdan et al., 2018) expresses the significance of exterior shading devices with regards to minimizing solar radiation and glare. The size, shape, and position of external shading device, are telling factors on its effectiveness (Cho and Kim, 2014).

Elzeyadi & Batool (2017) reported that in other studies (Raymond and Hattice, 2008) found lighter screen systems (Jali) consisting of external cables provide reduced cooling loads while maintaining privacy. When compared to external shading devices, they increase the building energy (Moeck et al., 2013; Batool, 2014). Studies focused on the vitality of overhangs state that: The humid zones require shade externally by adopting the use of large overhangs and other devices to render protection to the building (Fry and Drew, 1964). In regions with high rainfall, vernacular dwellings use a high thatched roof with eaves overhangs to protect walls and openings (Srivastava and Das, 2023).

Natural elements (Water and vegetation) are known, depending on the local climatic and environmental conditions, locations shaded by trees can be up to 5.6 °C colder than areas that aren't (Sanusi et al., 2017; Deilami et al., 2020). Coutts et al., (2013) also cited Larson et al., (2009) that xeric gardens, dryness, water constraints, and the deteriorated health of urban plants could all worsen urban warming and energy needs. See Table '1'.

Table 1. Shows the essential and reoccurring passive shading strategies for hot-humid climates according to past literatures.

S/No.	Authors recommendations for essential passive shading strategies for hot and humid climates	References
1.	External shading devices (Fins & Louvers) & Internal Shading Devices	Balaras et al. (2000), Shahdan et al. (2018), Cho & Kim (2014)
2.	Jali/Jali screens	Elzeyadi&Batool (2017), Batool (2014)
3.	Overhangs	Fry and Drew (1964), Srivastava and Das (2023)
4.	Natural Elements (trees& water)	Deilami et al. (2020), Coutts et al. (2013)

3.3 Case Study/

In addition to literature review, site observations were carried out to passive shading strategies employed by vernacular dwellings in Nigeria's hot and humid climate provide an excellent case study for architects and engineers seeking to develop sustainable buildings that minimize energy consumption. According to Adamu et al, and Jimoh (2020), the hot and humid climate of Nigeria places significant stress on buildings, which must remain cool and comfortable for occupants. Without adequate passive shading strategies, buildings in Nigeria face increased energy consumption due to the need for constant air conditioning to maintain comfort levels.

3.3.1. Case Study Selection Criteria

To study the use of passive shading strategies, for their distinct architectural styles, five buildings were examining from the major ethnic groups in Nigeria that adopted vernacular designs. See Figure '6'.



Figure 6. Illustrating a Map of Nigeria Showing the Broad Distribution of Major Ethnic Groups (Lodson et al., 2018).

1. The Hausa Vernacular Architecture:

The Hausas, sometimes referred to as Hausa/Fulani, are a linguistically and culturally homogeneous community that predominates in the northern region of Nigeria between latitudes 3.50°E and 11.0°E and 10.50°N and 14.00°N (Umaru et al., 2022). The Hausa people of Northern Nigeria have developed unique architectural styles that incorporate passive shading strategies. The common passive shadings features compose of the use of large, overhanging roofs and courtyards also helps to provide shade and ventilation, reducing the need for artificial cooling.

Building A has the main passive shading features as Jali screens on the south façade and overhangs at the first-floor level. See Figure '7'.

2. The Igbo Vernacular Architecture:

The Igbo people of Southeast Nigeria have developed an architecture that incorporates passive shading strategies to keep their homes cool. Their vernacular buildings have steep-pitched roofs with overhangs that provide shade and ventilation. The use of woven mats or palm fronds on the roof also helps to reduce heat gain. See Figure '7'.

Building B: the passive shading strategies here are, roof overhangs and trees.

3. The Fulani Vernacular Architecture (C): The Fulani people of Nigeria's northern region have developed an architecture that incorporates passive shading strategies to keep their homes cool. Their vernacular dwellings are made of grass and have conical roofs that provide shade and ventilation. The use of wooden screens on windows and doors helps to regulate airflow and reduce heat gain. See Figure '7'. Building C is the Fulani House, which utilizes a tall, conical roof with overhangs, and small windows with wooden screens (external shading devices/Jali screens) to provide shade and reduce solar heat gain;

4. The Benin Vernacular Architecture (D): The Benin people of Southern Nigeria have developed an architecture that incorporates passive shading strategies to keep their homes cool. Their vernacular dwellings have large, overhanging roofs that provide shade and rain protection. The use of courtyards and verandas also helps to provide ventilation and reduce heat gain. See Figure '7'.

Building D: the shading strategies used are overhanging thatch roof and trees (natural strategies).

5. The Yoruba Vernacular Architecture (E): The Yoruba people of Southwest Nigeria have developed an architectural style that incorporates passive shading strategies to keep their homes cool. Their vernacular dwellings have deep verandas and courtyards that provide shade and natural ventilation. The use of wooden louvers (jali screens), shutters, and screens on windows and doors also helps to regulate airflow and reduce heat gain.

Building E: the passive shading strategies utilized here are, external shading devices such as concrete window awnings, jali screens, and natural elements (trees). See Figure '7'.

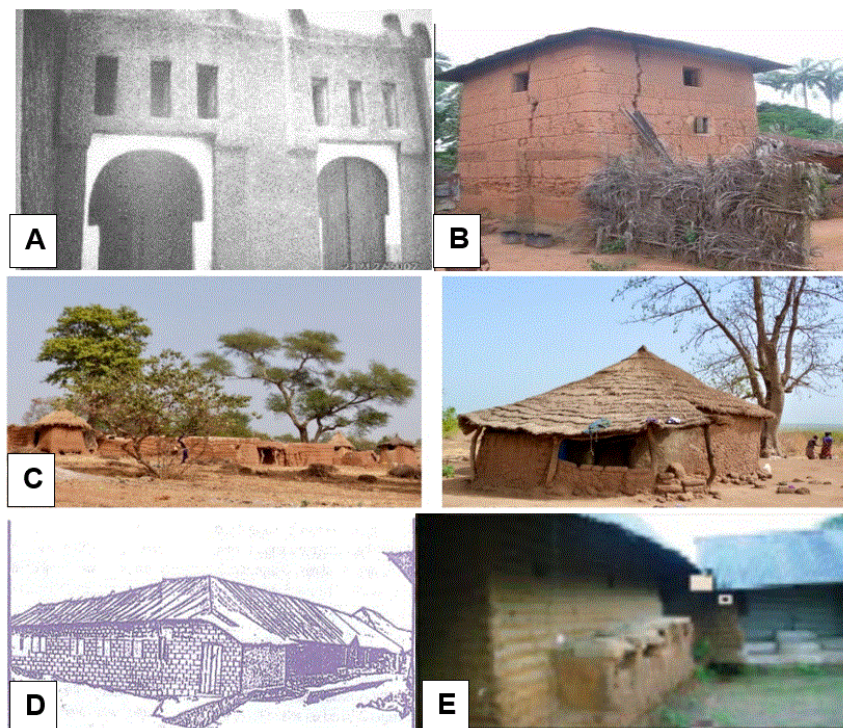


Figure 7. Building 'A' shows the application of jali screens and overhangs (Garba, 2003).

Building 'B' Showing an Igbo vernacular architecture (Okoye & Ukanwa 2019).

Building 'C' Shows the passive strategies for shading.




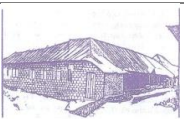

Illustration of Building 'D' (Ekhaese et al., 2021).

All five buildings use passive shading strategies that are indigenous to Nigeria's hot and humid climate, demonstrating successful integration of vernacular designs. These buildings provide architects and engineers with examples of how passive shading strategies can be used to lower energy use in conditions like that. In addition, these vernacular buildings can also guide designers to incorporate innovations from vernacular architecture into contemporary buildings.

These examples demonstrate how vernacular designs can be incorporated into modern building techniques in order to achieve more sustainable living environments. As architects and engineers continue to develop new ways to reduce energy consumption, passive shading strategies remain a critical consideration for designers seeking to create energy-efficient buildings.

The result from the case study analysis presents the most frequently devised passive shading strategies in the hot and humid vernacular and vernacular dwellings of Nigeria. See Table '2'.

Table 2. Objective indicators. Summarizing the result from the cases (A to E) studied through field observations.

Study case	A	B	C	D	E
Passive Shading Strategies					
Shading Devices (External & Internal)	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
Jali screens	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
Overhangs	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
Natural Elements (Trees)			<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>

4. Analyses, Findings, and Discussions

4.1 Analytical (Objective) Findings

As aforementioned, the passive shading strategies adopted within the vernacular buildings of the five selected local cases studied in the hot and humid climate of Nigeria were: Overhangs; J; External shading devices; Jali screens; Natural elements. It was observed that 80% of the buildings used overhangs. 60% of the buildings adopted external shading devices. 60% of the buildings used Jali screens. 40% used natural elements (trees). According to the results, overhangs, Jali screens, and external shading devices are the predominant passive shading strategies utilized within the vernacular and vernacular buildings in Nigeria. See Figure '8'.

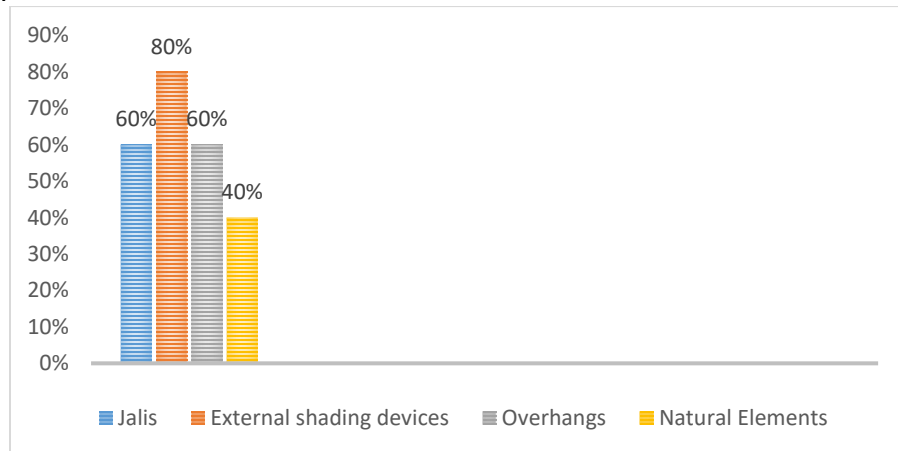


Figure 8. Shows results of case study analysis.

4.2. Interview (subjective) Findings

Answers (information) obtained from semi-structured Interviews are on the questions were analysed using Likert's scale which collects qualitative ordinal data and gives quantitative results.

The data from the conducted interview which granted a basis for the calculation of the mean or mode score and conducted statistical tests to identify any significant differences in satisfaction levels among different groups of professionals.

The criteria for interviewee selection was on the basis for experienced professionals within the context (Nigeria) for the study. This because they would be best suited to provide candid information regarding the study. Three questions were designed so as to acquire the necessary data from fifteen (15) selected professional participants in the field of architecture and building constructions. Divided to five each, academicians, architects, and engineers, from different public, and private sectors. See Table '3'.

Table 3. Subjective indicators. Interviewee professionals and the percentage of each profession.

Professionals	Number of participants	Percentage
Architects	5	33.33%
Engineers	5	33.33%
Academicians	5	33.33%
TOTAL	15	100%

The interviewees were asked to rate the following passive shading strategies from the cases studied of vernacular buildings in terms of their effectiveness (in terms of the energy efficiency) and adaptability (in terms of the flexibility to the dynamics of periodic changes). See figure '9'.

The rating was done on a scale of 1 to 5, where:

- 1 = Highly ineffective & Highly unadaptable
- 2 = Ineffective & Unadaptable
- 3 = Neutral
- 4 = Effective & Adaptable
- 5 = Highly effective & Highly adaptable

The first question was *which amongst the passive shading strategies mentioned in the case study analysis do you consider the effectiveness of high-rise residential buildings of the hot-humid climate of Nigeria?*

The second question was *which amongst the passive shading strategies mentioned in the case study analysis do you consider the adaptability for high-rise residential buildings of the hot-humid climate of Nigeria?*

4.2.1 Results of Interview

1. Architects:

The first interview questions with the five (5) architects revealed the *effectiveness* rating. See Table '4'.

Table 4. Summary of Likert's scale rating for of the effectiveness levels of the passive shading strategies by the architects.

Effectiveness Ratings	1	2	3	4	5	Likert formula	Result	Scale
Jali Screen	0	0	1	3	1	20	4	4
Natural elements	0	0	3	2	0	17	3.4	3
Shading devices	0	0	2	3	0	18	3.6	4
Overhangs	0	0	3	2	0	17	3.4	3

The second interview question results with architects for the ratings based on the *adaptability* levels are revealed. See Table '5'.

Table 5. Summary of Likert's scale rating for of the adaptability levels of the passive shading strategies by the architects.

Adaptability Ratings	1	2	3	4	5	Likert formula	Result	Scale
Jali Screen	0	0	2	3	0	18	3.6	4
Natural elements	0	2	3	0	0	13	2.6	3
Shading devices	0	0	2	3	0	18	3.6	4
Overhangs	0	1	2	2	0	16	3.2	3

2. Engineers:

They revealed that the *effectiveness* rating for passive shading strategies from vernacular buildings for reducing energy demand. See Table '6'.

Table 6. Summary for engineers view on the effectiveness rating using Likert's scale.

Effectiveness Ratings	1	2	3	4	5	Likert formula	Result	Scale
Jali Screen	0	0	2	3	0	18	3.6	4
Natural elements	0	0	3	2	0	17	3.4	3
Shading devices	0	0	0	2	3	23	4.6	5
Overhangs	0	0	2	3	0	18	3.6	4

The second interview question results with engineers for the ratings based on the *adaptability* levels revealed. See Table '7'.

Table 7. Summary for engineers view on the adaptability rating using Likert's scale.

Adaptability Ratings	1	2	3	4	5	Likert formula	Result	Scale
Jali Screen	0	0	5	0	0	15	3	3
Natural elements	0	0	0	3	2	22	4.4	4
Shading devices	0	0	0	2	3	23	4.6	5
Overhangs	0	0	2	3	0	18	3.6	4

3. Academicians:

They revealed that the *effectiveness* rating for passive shading strategies from vernacular buildings for reducing energy demand. See Table '8'.

Table 8. Summary for academicians view on their effectiveness rating using Likert's scale.

Effectiveness Ratings	1	2	3	4	5	Likert formula	Result	Scale
Jali Screen	0	0	2	3	0	18	3.6	4
Natural elements	0	0	3	2	0	17	3.4	3
Shading devices	0	0	0	2	3	23	4.6	5
Overhangs	0	0	3	2	0	17	3.4	3

The second interview question results with academicians for the ratings based on the *adaptability* levels. See Table '9'.

Table 9. Summary for academicians view on their adaptability rating using Likert's scale.

Adaptability Ratings	1	2	3	4	5	Likert formula	Result	Scale
Jali Screen	0	0	3	2	0	17	3.4	3
Natural elements	0	0	3	2	0	17	3.4	3
Shading devices	0	0	2	3	0	18	3.6	4
Overhangs	0	0	2	4	0	22	4.4	4

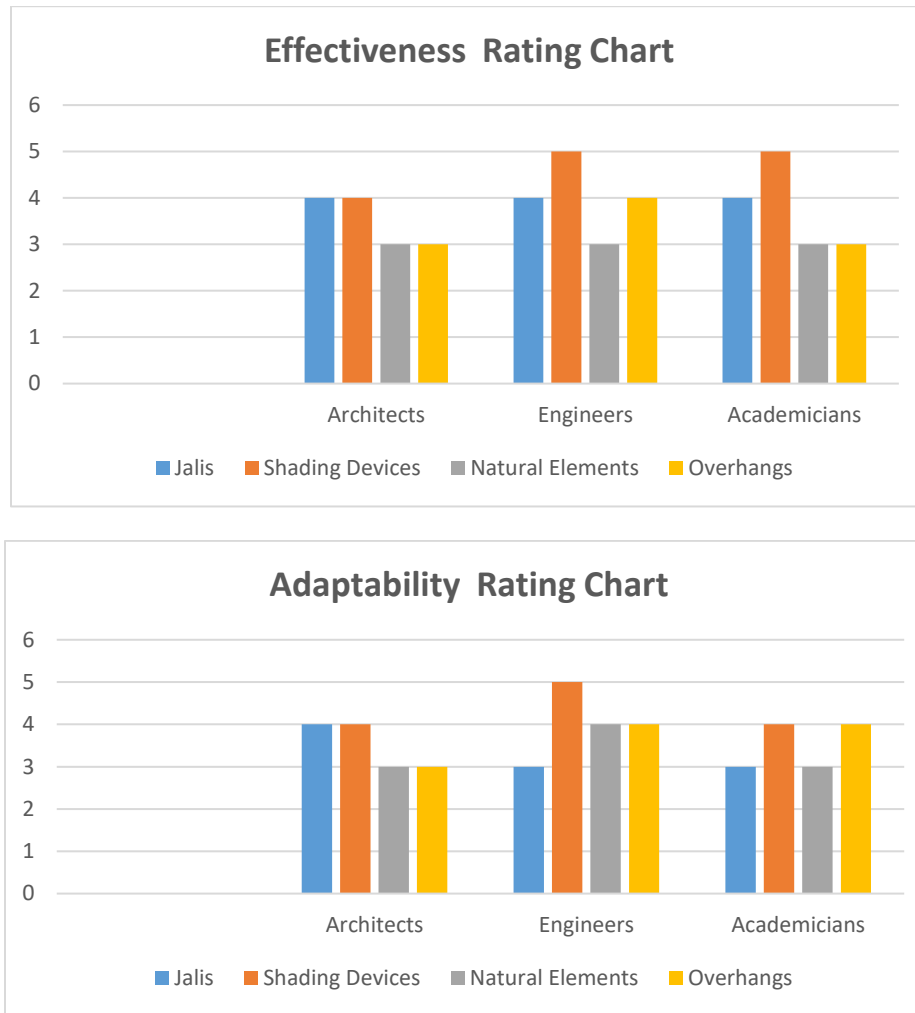


Figure 9. (a) Summary opinions by 15 professionals about the effectiveness rating for passive shading strategies from vernacular buildings for contemporary high rise residential buildings
(b) Summary opinions by 15 professionals about the adaptability rating for passive shading strategies from vernacular buildings for contemporary high rise residential buildings.

4.4. Discussion

Passive shading strategies play a crucial role in optimizing energy use in buildings located in hot and humid climates, such as those found in Nigeria. The study focused on understanding the implications of these strategies by examining vernacular buildings in Nigeria. The data collection process involved conducting case studies of five buildings and conducting semi-structured interviews to gauge the effectiveness and adaptability of the shading strategies. The findings from these studies shed light on the significance of external shading devices, overhangs, natural elements like trees and water, and jali screens in mitigating solar heat gain and providing thermal comfort. Incorporating these strategies in contemporary architectural designs can provide useful insights for energy optimization in buildings while also drawing inspiration from Nigeria's rich vernacular heritage. The significance of the study is:

1. To contribute to sustainable architecture;
2. Passive shading strategies can reduce energy consumption and improve indoor comfort, which is crucial in regions with high temperatures and humidity;
3. The study of vernacular buildings can provide insights into how local communities have adapted to their environment over time.

The analysis of the results from the cases study implies that 80% of the vernacular buildings in Nigeria used overhangs as a passive shading strategy. 60% each of the buildings used external shading devices and jali screens while 40% of the buildings implemented natural elements as passive shading strategies.

The answers given by the professionals to the interview questions were based on the effectiveness and adaptability of the selected passive shading strategies and were rated using the Likert scale. The ordinal numbers for the rating were 1 to 5, in ranking order from highly ineffective and highly unadaptable to highly effective and highly adaptable passive shading strategies respectively for reducing the energy demands in buildings, thus improving thermal comfort indoors.

The analysis from one-way ANOVA revealed the following passive shading strategies:

1. Jalis Screen was found to have an F-statistic of 0.20 and 0.59 for effectiveness and adaptability respectively, less than the critical F-value, 3.97. These interpret that there are no significant differences between and within the groups of experts in both the effectiveness and adaptability of the Jalis screen.
2. Internal shading devices were found to have no significant differences in both effectiveness and adaptability levels.
3. Overhangs were found to have no significant differences in both effectiveness and adaptability levels.
4. Natural Elements were found to have no significant differences in both effectiveness and adaptability levels.

The null hypothesis failed to be rejected in all of these cases.

5. Conclusion

This article aimed to investigate the implications of passive shading strategies in high-rise residential buildings of hot and humid climates, with a particular focus on lessons that can be learned from vernacular dwellings in Nigeria. Through interviews and a comprehensive review of the literature, it was found that passive shading strategies can play a significant role in energy optimization in such climates.

The research questions posed in this study were answered by examining the different passive shading strategies employed in vernacular buildings across Nigeria. It was observed that these strategies effectively with rankings, mitigate direct solar radiation, reduce heat gain, and enhance indoor thermal comfort. According to the study, the most effective and adaptive passive shading strategy for reducing solar heat gain by high-rise residential buildings in hot and humid climates of Nigeria is the use of shading devices.

To the point of the results derived from the use of one-way ANOVA, it is safe to conclude that there are no significant differences in the effectiveness and adaptability with respect to the use of the aforementioned vernacularly derived passive shading strategies for energy optimisation in hot and humid climates of Nigeria. The implementation of shading passive strategies in contemporary building designs in Nigeria can lead to an improved indoor thermal comfort level.

Properly implemented shading passive strategies can effectively contribute to a sustainable and eco-friendly environment.

The study proves that, vernacular dwellings in Nigeria offer valuable lessons and insights that can be adopted to optimize energy efficiency and thermal comfort in modern buildings in similar climatic conditions. Finally, future research might further examine the impact of numerous design factors, including building orientation, window size and placement, and shading device types, on the efficiency of passive shading techniques in energy optimisation. Systematic experimental and simulation studies could be used to accomplish this.

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Conflict of Interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors/s.

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