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Use of Passive Cooling Strategies in Selected Mega-Churches within Lagos-Ogun Megacity, Nigeria

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Abstract Typically, church buildings are large spaces characterized by infrequent usage at given intervals. Quite often, modern churches rely on air conditioning for the indoor comfort of occupants, which presents challenges for environmental sustainability. However, church buildings, especially in tropical regions, have also adopted passive cooling strategies both as an alternative to air conditioning and as a complement to it, where it helps to reduce air conditioning load and promote environmental sustainability. The aim of this study is to evaluate the use of the passive cooling strategies for achieving environmental sustainability in selected mega-churches in Lagos-Ogun megacity, Nigeria. Qualitative research method was used in this study and primary data was obtained using an observation guide in order to document the passive cooling strategies used in the selected four churches. The results were analyzed using descriptive analysis and presented in texts, plates and tables. From the result, the study found that some of the passive cooling strategies found in literature were employed in the four selected mega-churches although they were not adequate to meet the cooling needs of the large congregation. This resulted in the selected mega-churches relying fully on air-conditioning. The results also showed that passive cooling strategies can be very relevant even in large spaces where they mitigate the air conditioning load. It also indicates that passive strategies can be relied upon when the buildings are used outside the conventional periods, especially for smaller groups of church members. Based on the findings, the study recommends that proper attention should be paid to integrating passive cooling strategies at the initial stage of the design. Additionally, thermal simulations can be carried out to examine the effectiveness of the passive cooling strategies utilized.

Keywords Church Buildings, Environmental Sustainability, Passive Cooling, Tropical Climate

1. Introduction

In recent years, the use of air conditioning systems to cool buildings has seen a significant increase worldwide. This trend has particularly affected developing countries, where the high cooling load requirements of buildings have exacerbated energy crises during summer seasons over the past two decades [1]. Unfortunately, this has led to environmental pollution, raising concerns about resource depletion and serious implications for the environment, including global warming, climate change, and ozone layer depletion [2] [3].

As the 21st century continues to unfold, the relationship between humans and the environment will become increasingly critical [4]. The emphasis on sustainable development has arisen due to the significant impact that buildings have on the environment [5]. While the primary goal of buildings is to provide a comfortable environment for their occupants, climate change and global warming have made this increasingly difficult to achieve through natural means. This has resulted in a growing reliance on artificial energy sources to maintain indoor comfort, including lighting, heating, and cooling systems [6]. As reported by Al-Shargabi [7], the building and construction industry contributes over 40% of the overall consumption of energy and nearly 35% of carbon dioxide emissions. This makes it a primary contributor to global warming, climate change, and air pollution. Contemporary building designs often prioritize aesthetics over designing for the local environment, leading to high energy consumption [8]. The issue of environmental sustainability in building design has become increasingly important, especially in tropical regions where the climate can be harsh and challenging.

In order to achieve a sustainable building in the tropical climate, one of the critical considerations is passive cooling. Passive cooling strategies involve designing buildings to work with the local climate. It plays a major role in achieving environmental sustainability in buildings, due to the high energy demand of mechanical cooling in buildings [9]. Passive cooling techniques are non-mechanical solutions that provide a comfortable temperature within a building while considerably reducing the environmental effect of buildings. These strategies can minimize a building's maximum cooling demand, reducing the quantity of air conditioning systems required and the time it is normally required [10]. Architects and building designers are usually expected to consider passive cooling strategies that help buildings to adapt to the prevailing climate from the onset [11]. According to a study carried out by Sekatia [9], it was observed that building designs must align with the local climate to promote environmental sustainability, irrespective of the building type, which includes churches.

Nabilah [8] found that religious buildings have uncommon times of use varying from full occupancy to none at all, which results in lower overall energy consumption when compared with other commercial buildings. However, the periods of full occupancy are characterised by high energy use intensity. In general, the impact of global warming, developments in everyday life, and the expansion of communication systems have resulted in increased energy consumption patterns, which inevitably lead to depletion of fossil fuels and result in negative environmental impact [8]. The lack of attention to the energy performance of buildings in general may lead to negative impact on the users' physiological comfort, ability for mental and physical labor, health, and leisure [5]. This also applies to churches, especially mega-churches which accommodate large numbers of worshippers.

A mega-church building is a religious building with a congregation attendance of 2000 or more [12]. In spite of the fact that massive buildings, such as churches, take up a substantial amount of floor space in public buildings, little attention has been paid to the energy performance of these building types [13]. Some studies have shown how passive design can be applied in church buildings. Some of such studies include: [13] [9] [8] [14]. Despite the contributions these studies have made to knowledge, they were found not to have focused on the assessment of passive cooling strategies towards achieving environmental sustainability in mega-churches, which is the gap this study was conducted to fill.

Therefore, this study is aimed at evaluating the use of passive cooling strategies for achieving environmental sustainability in selected mega-churches in Lagos-Ogun megacity, Nigeria. The Lagos-Ogun mega-city axis hosts a reasonable number of mega-churches relevant to this study. In order to address the aim of the study, the following research objectives were formulated:

(i) to identify the passive cooling strategies that are effective for achieving environmental sustainability in buildings, and
(ii) to examine the extent to which selected mega-churches in the study area applied the identified passive cooling strategies.

The study provides a valuable resource for built environment stakeholders who seek guidance on effective passive cooling strategies for achieving environmental sustainability in building design, specifically for churches. The study supports the seventh of the 17 Sustainable Development Goals (SDGs), which aims to provide reliable, affordable, sustainable, and modern energy for all. As an accessible learning material, the research also helps to advance the fourth target of the 17 SDGs, which seeks to provide lifelong learning opportunities for all.

2. Literature Review

2.1. Passive Cooling Strategies

According to a study conducted by Vella [13], specific passive strategies can improve indoor temperatures and create a more comfortable atmosphere. These strategies include building orientation, building form, thermal insulation, natural ventilation and the use of vegetation as stated by Nwalusi [11]. The detailed passive cooling strategies for designing to climate and achieving indoor comfort in buildings are discussed subsequently.

2.1.1. Proper Building Orientation

According to Erebor [3], it has been recognized that proper building orientation on site is a crucial strategy for reducing heat gains within a building. A well-oriented building can significantly improve the comfort of its inhabitants. In hot climates, a building's orientation should be based on solar considerations, given that temperatures can reach up to 40 degrees Celsius during the day. From Akande's findings in 2010 [5], the longer facade of the building should face north and south, as can be seen in Figure 1. The significance of orientation in a building must be addressed from the beginning, when the architect plans the position of the structure on the site, with the goal of ensuring optimal comfort for occupants in the interior areas.

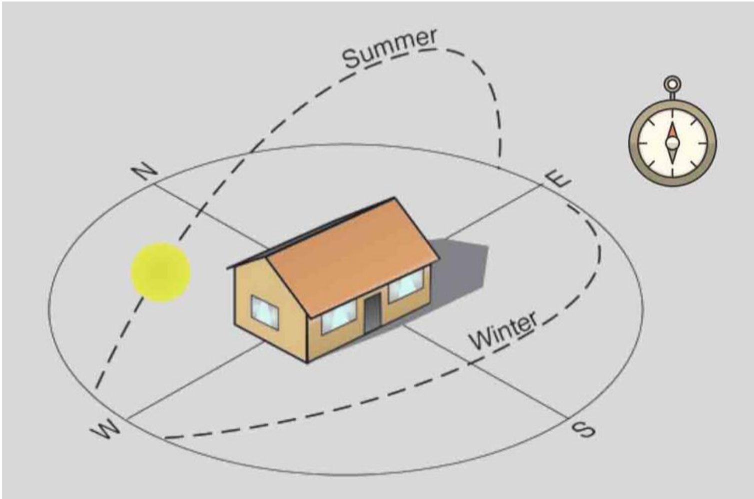

Figure 1. The proper solar orientation. (Source: www.civilseek.com)

2.1.2. Building Form

The shape of a building has a huge potential to reduce the amount of energy it consumes. However, building designs are influenced by various factors, such as planning considerations, building type, use, feasibility, and initial cost. Certain building designs like slender high-rise towers can significantly increase the ratio of envelope area to volume, thereby improving the energy efficiency of the structure. Inusa [15] suggests that elongated designs are favourable for all types of passive solar buildings, particularly day-lit structures, due to their increased ability to utilize sunlight. It has also been found that an elongated building can save up to 15-25% more energy compared to a compact building of the same size [16].

2.1.3. Solar Shading

Shading is a bioclimatic design strategy that keeps buildings from absorbing radiation from the sun. The implementation of solar shading strategies is critical in minimizing building cooling demands, especially in warmer regions with high external temperatures. Given that contemporary structures are created with more exterior glass surfaces, the importance of solar shading methods has increased significantly as a strategy to reduce energy consumption [17].

According to Kamal [2], shading can be categorized as follows:

(i) Overhangs: Properly designed shading elements such as overhangs, louvers, and awnings can significantly decrease the building's maximum heat gain, lower cooling requirements, and enhance the quality of natural lighting inside the building. These shading devices may be integrated into the building's structure or placed separately from the building facade as shown in Figure 2.

(ii) Roof Shading: One way to reduce heat gain on roofs is to use a roof covering made of materials like concrete, plants, canvas or earthen pots to shield the roof from direct sunlight, as can be observed in Figure 3. Concrete or galvanized iron sheet roofs provide excellent protection, but roofs covered with deciduous plants and creepers are better alternatives. The water vapour that evaporates from the plant surfaces lowers the temperature of the roof, which can be cooler than the daytime air temperature.

(iii) Vegetation: Using trees and plants for shading is an effective strategy for saving energy in buildings. Landscaping with vegetation, especially trees, can significantly minimize heat gain through walls, roofs and windows. Trees can also cool the air temperature around them by up to 5°C by providing shade and releasing water vapour through a process called evapotranspiration [18]. Figure 4 shows the use of trees as shading.

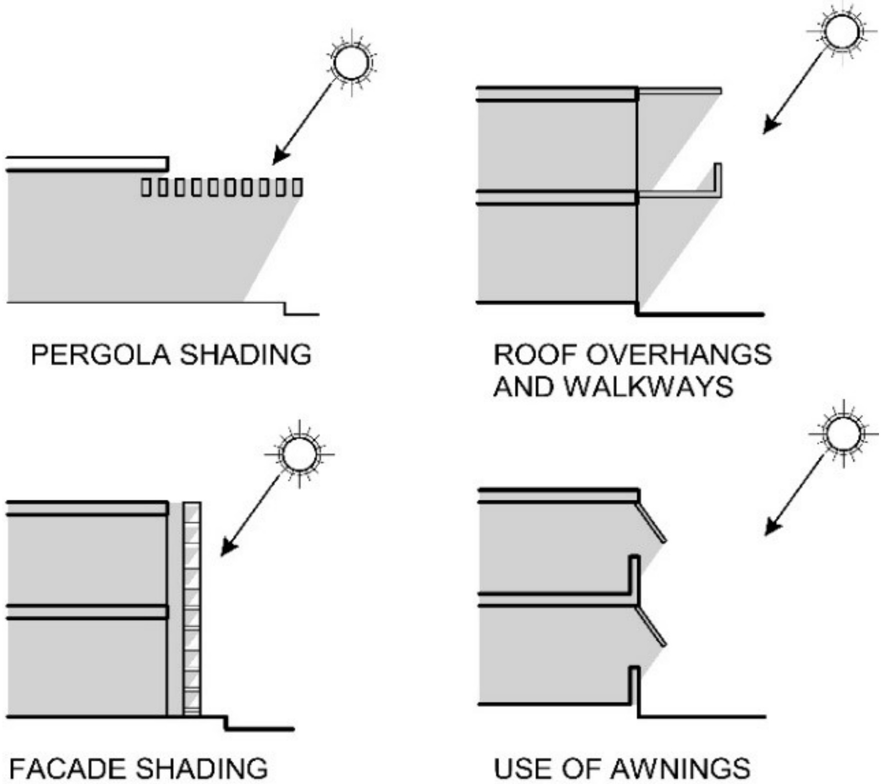

Figure 2. Overhangs and façade shading (Source: Kamal [2])

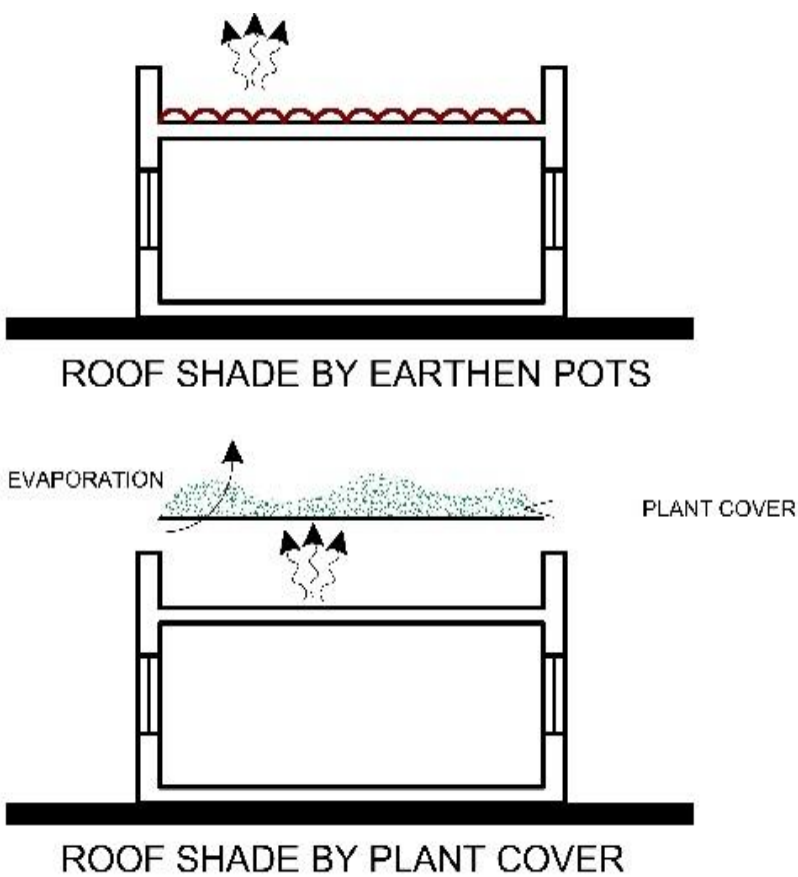

Figure 3. Types of roof shading (Source: Subramanian and Divya [18])

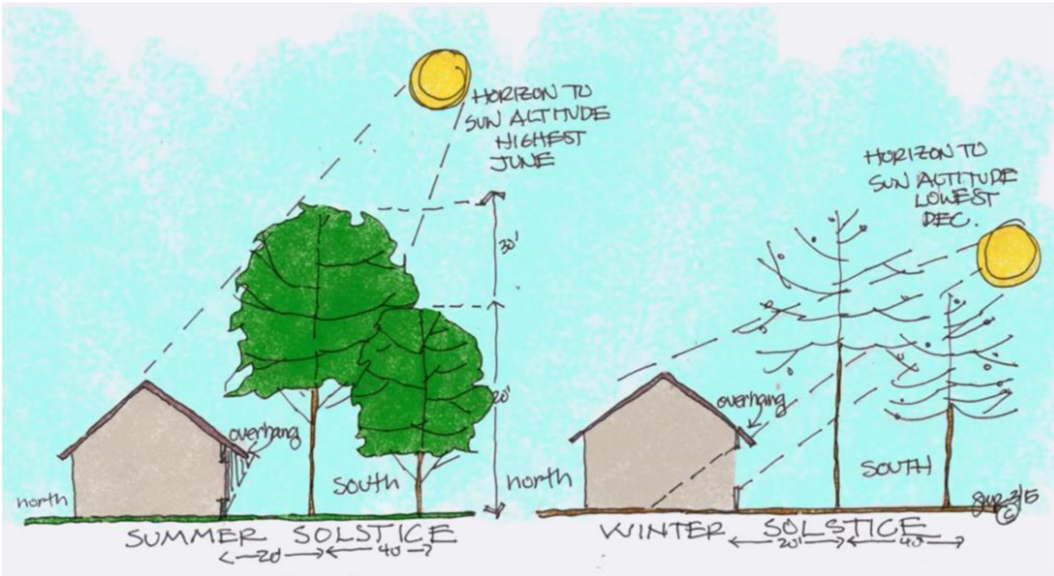

Figure 4. Use of trees for shading (Source: www.purdue.edu)

2.1.4. Natural Ventilation

According to Hayati [14], natural ventilation is the oldest and most widely utilized type of ventilation in history. The fundamental goal of ventilation is to deliver fresh air while also removing air contaminants from indoor environments. Mechanical ventilation is accomplished via the use of fans, ducts, and input and outlet openings, whereas natural ventilation is accomplished by the use of purpose-designed openings such as window slots, open doors and windows, grills, chimneys or stacks, wind towers, and other purposeful routes. Natural ventilation is classified into three types: single-sided ventilation, cross-ventilation, and stack ventilation [17].

Sekatia [9] conducted a study on the Bogor Cathedral Church, a historical building equipped with a low ventilation passive cooling system, adjustable, open or closed, and located at the bottom of the walls at a height of approximately 600mm from the floor. The findings of the study revealed that low ventilation successfully lowered the effective temperature of the building, resulting in cooler indoor temperatures as a result of stack cooling effect.

A major factor that could affect natural ventilation is the window to wall ratio. In hot environments, the demand of cooling energy increases with a higher window-to-wall ratio, particularly on the southern facade, as this leads to more passive solar heating. Because the East and South orientations are the most vulnerable to solar heat gain, glazed systems in these orientations should be avoided. According to Fernandez [19], a North-to-South orientation is best in tropical climates, with external walls and a window-to-wall Ratio being less than 20%. Additionally, the use of light colours is preferred in hotter climate zones to increase solar reflectance.

Other types of Ventilation techniques include:

Induced ventilation: Solar chimneys and wind towers are two devices that can be used to improve natural ventilation. The solar chimney is designed to naturally draw hot air out of a building by using the upward movement of hot air created by solar heating. This process creates a vacuum that pulls cooler air from outside the building into the bottom of the chimney, replacing the hot air inside. Figure 5 shows ventilation through solar chimney. The Wind Tower, on the other hand, takes advantage of wind to cool hot air inside the tower. Hot air enters the tower through openings and is cooled as it rises, creating a flow of air that can be used to cool the living area. Wind helps to cool the air more efficiently and increase the airflow through the tower [2].

Ground Cooling: Musdinar [20] and Zhang [21] noted that beyond depths of 4 to 5 meters, the temperature of the soil remains relatively constant throughout the year, without daily or seasonal fluctuations. Hence, underground or partially buried buildings can offer natural cooling during the summer and heating during the winter. In addition, Kamal [2] explains that air moving through a tunnel or buried pipe at a shallow depth can become cooler during the summer and warmer during the winter as illustrated in Figure 6.

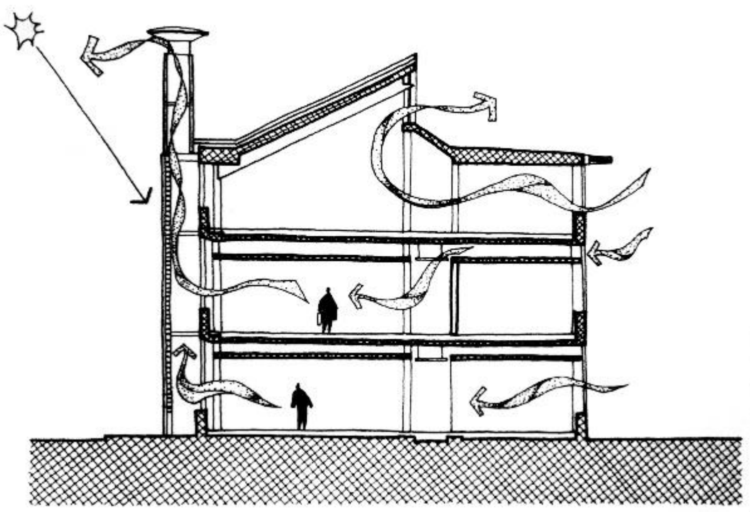

Figure 5. Induced and roof ventilation (Source: Inusa and Alibaba [15])

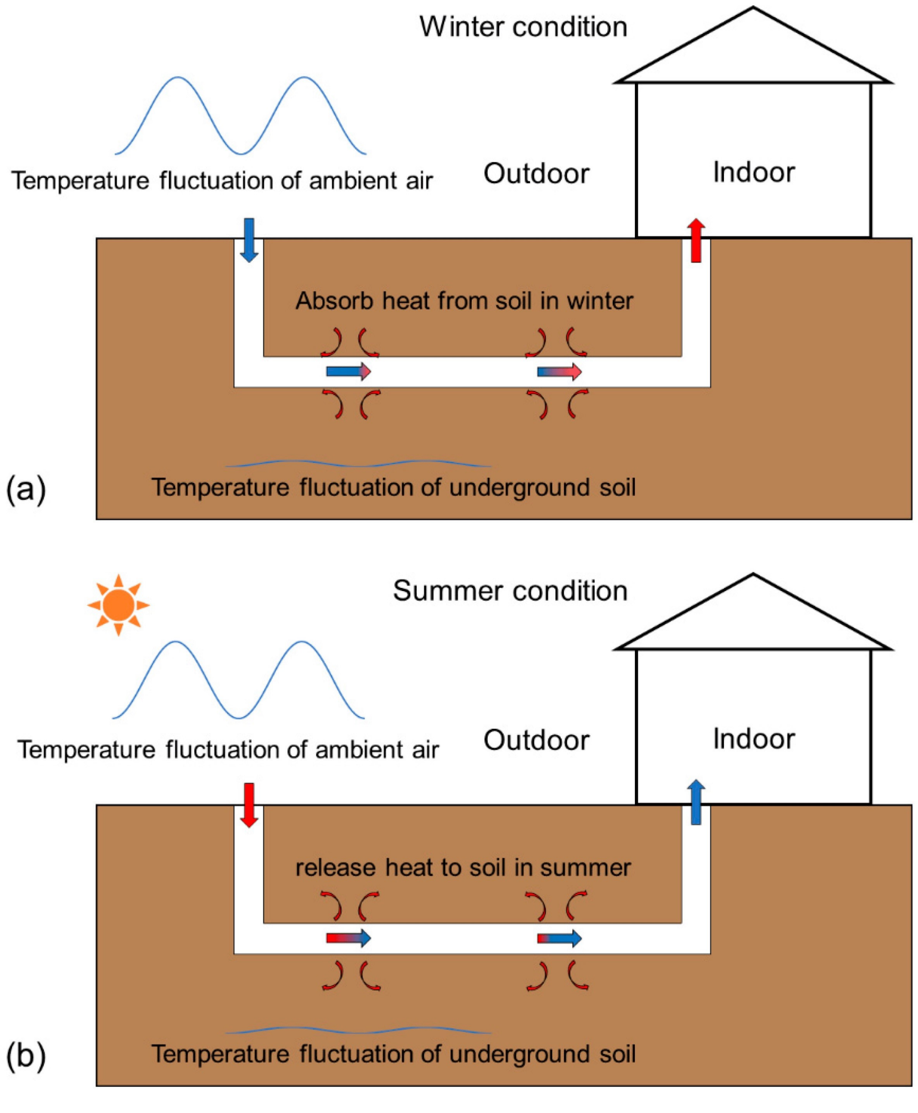

Figure 6. Ground cooling (Source: Zhang et al., [21])

(i) Roof Ventilation: Zune [22] emphasized that the use of multi stage roof allows roof ventilation through roof vents using the stack cooling effect, offering an opportunity to enhance indoor comfort in tropical climates.

(ii) Night Ventilation: Night ventilation is a natural cooling process that cools down a building's mass through radiation to the night sky. It creates a heat sink for thermal gains in the following days. This technique pre-cools a building using outdoor airflow at night and allows for radiant cooling during the day when the building is occupied. The effectiveness of night ventilation was assessed in three different climates, and it was found that the strategy has a positive impact on indoor conditions, but it may not be enough to cool the space on its own [23] [24] [13].

2.1.5. Vegetation and Landscaping

One way to enhance the design of buildings in hot climates is through the integration of vegetation, both internally and externally. By incorporating vegetation, buildings can benefit from shade and cooler temperatures throughout the year. Surrounding buildings with vegetated screens can also create a natural cooling effect that shields them from direct sunlight, as can be seen in Figure 7. According to Kamal [2], planting trees around buildings can result in several benefits, including energy savings, noise reduction, pollution reduction, temperature and humidity modification, and psychological benefits for people. Proper tree plantation has been found to reduce cooling loads by 10% to 40% in a house.

Plants can also be used as parts of the building as green roof and green walls, improving its effect. To enhance the aesthetics of buildings, greening systems such as Green Roofs and Green Walls are commonly employed [25]. Recently, these systems have gained popularity due to their benefits that are not limited to social, economic, and environmental aspects. The greening systems generally refer to roofs and walls of a building that are covered with diverse types of vegetation. They consist of different layers, including vegetation, insulation, filter, substrate, and drainage [26].

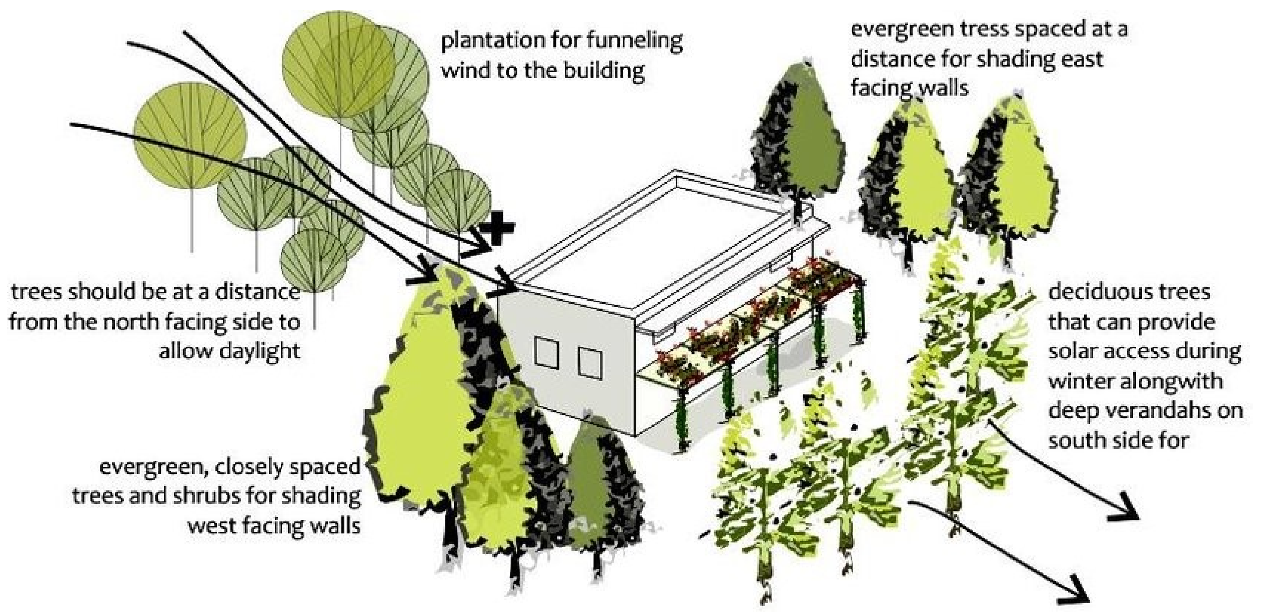

Figure 7. Use of vegetation (Source: Nisar et al., [26])

2.1.6. Thermal Mass and Insulation

The concept of thermal mass relates to the material used in the building envelope that can help regulate temperature changes throughout the day by absorbing heat during periods of high solar radiation and releasing heat as the atmosphere cools down. In this respect, Abbakyari [27], proposed compressed earth bricks as alternative to conventional sandcrete blocks in tropical buildings.

Insulation is an effective way to reduce heat gain and loss in buildings by controlling the interior temperature and preventing the transfer of heat between the interior and exterior. Insulation is the most effective when installed in wall cavities as indicated in Figure 8. Various materials like aerogels, mineral wool, wood fibre, polyurethane, fiberglass, cellulose, and calcium silicate can be used as thermal insulation in the building envelope.

The selection of glazing systems is crucial in reducing heat gain/loss through windows, and factors such as U-value, WWR, SHGC, visible transmittance, and orientation should be considered. Triple glazing was found to be the most effective in enhancing indoor thermal comfort for average air temperature and solar gains, while roof and wall insulation was more effective for average relative humidity and total fresh air, from a study conducted by Yassa [28]. Studies have shown that reflective roof material and balcony presence acting as a buffer space greatly influences the system, with insulation reducing the number of overheating days by 21.43% and removing the balcony increasing it by 19.94% due to reduced internal ventilation [17] [29] [30] [13]. Solar shading, thermal insulation, and natural ventilation can all reduce indoor temperatures, according to Chen [31].

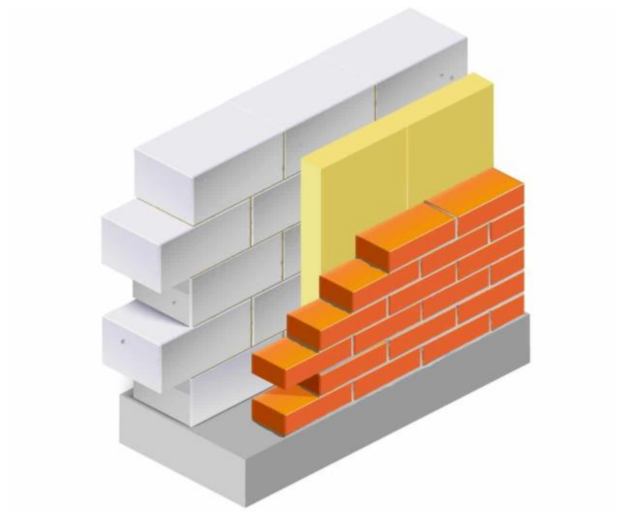

Figure 8. Wall cavity insulation (Source: karnheathltd.com)

2.1.7. Evaporative Cooling

Evaporative cooling is a technique that reduces the temperature of indoor air by evaporating water, making it beneficial in tropical regions with high outdoor temperatures. This process cools the air by utilizing the heat present in it to evaporate water, resulting in a decrease in the temperature of the air and the interior space. The rate of evaporation can be enhanced by increasing the contact between water and air. Placing a body of water near the building, such as a pond, lake, or river, or constructing a fountain in a courtyard, can give a cooling effect, as can be observed in Figure 9. According to Kamal [2], evaporative cooling can be used in two ways, which includes:

(i) Passive Downdraft Evaporative Cooling: Passive downdraft evaporative cooling systems involve a tower that uses water distribution at the top to create cool air for the building. Water is sprayed or dripped on the tower, which helps to cool it down and supply fresh, cool air inside the building.

(ii) Roof Surface Evaporative Cooling: To cool roof surfaces, a cost-effective method is to spray water over materials that retain water. The wet surface of the roof allows for evaporation, which cools the roof by drawing latent heat from the surface as the water evaporates. This reduces heat gain and helps to lower the temperature of the roof.

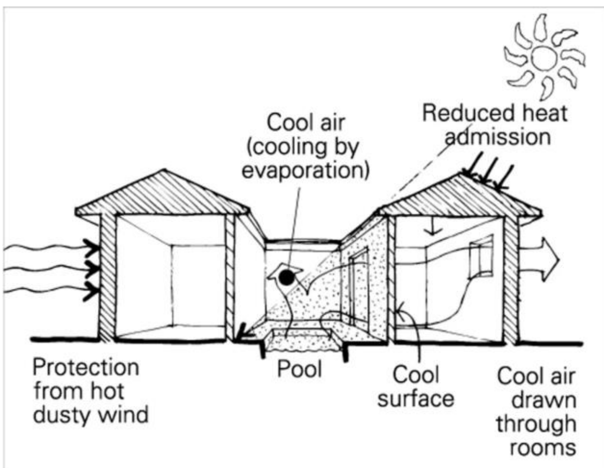

Figure 9. Evaporative cooling (Source: Subramanian and Divya [18])

3. Materials and Methods

This study focused on the evaluation of the use of passive cooling strategies for achieving environmental sustainability in selected mega-churches, therefore, the qualitative research method was adopted for this study. An observation guide was used to assess the extents to which the passive cooling strategies were used in the selected mega-churches.

The study area for the research is the Lagos-Ogun megacity. This is one of the largest and fastest-growing urban areas in Nigeria. It comprises Lagos State, one of the most populous states in Nigeria, and some parts of Ogun State, a neighboring state with a rapidly expanding population. The study area was selected due to the presence of many notable mega-churches located therein. Purposive sampling was used in the study, based on three major selection criteria. Firstly, the church capacity must be above 7000. Secondly, the building must be purpose-built to be a church. The recency of the church building construction was also considered. Investigating the latest construction techniques and technology employed by the designers will indicate the level of compliance with new technology that hinges on sustainability. Table 2 shows the selected mega-churches which were derived from the sampling frame of mega-churches with capacity of 7000 seating capacity in Lagos-Ogun Megacity as shown in Table 1.

The observation schedule focused on the passive cooling strategies gleaned from literature to keep the study focused on the vital aspects, in order to successfully identify the presence of those specific strategies. The findings were analyzed using descriptive analysis and conclusions were drawn to ascertain the extent to which the selected mega-churches applied the passive cooling strategies found in literature.

Afterwards, the church building with the most adopted passive strategies was identified for more indepth study. The indepth analysis is limited to the tangible observations and physical assessments feasible on-site.

A digital camera was used to take photographs of existing features in the selected mega-churches. The findings were presented using texts, tables and plates for clarity and easy understanding.

Table 1. The sampling frame of megachurches above 7000 seating capacity in Lagos and Ogun state, Nigeria

SN	Name of Church	Capacity	Location
1.	Faith Terbanacle Canaan land	50,000	Ota, Ogun state
2.	Deeper Christian Life Ministry	30,000	Gbagada, Lagos state
3.	National Temple, Apostolic church	10,000	Ketu, Lagos
4.	Christ Embassy Believer’s Love	20,000	Ikeja, Lagos
5.	The Synagogue Church of all nations	15,000	Egbe, Lagos
6.	House on the Rock HQ	10,000	Lekki, Lagos
7.	The Redeemed Evangelical Mission	10,000	Gbagada, Lagos
8.	Fountain of Life Church	8,000	Ilupeju, Lagos

Table 2. Selected megachurches in Lagos-Ogun megacity.

SN	Name of Church	Capacity	Location
1	Faith Tabernacle, Canaan land.	50,000	Ota, Ogun state
2	Deeper Christian Life Ministry.	30,000	Gbagada, Lagos state
3	House on the Rock HQ.	10,000	Lekki, Lagos state
4	Fountain of Life Church.	8,000	Ilupeju, Lagos state

4. Results and Discussion

The study investigated the passive cooling strategies utilized in the selected mega-churches, and the findings are presented in the sub-sections below.

4.1. Building Characteristics of the Selected Mega-Churches

4.1.1. Faith Tabernacle, Canaan Land

Faith Tabernacle is a mega Pentecostal Church building that serves as the headquarter for the Living Faith Church Worldwide. It is situated at Canaan land, kilometre 10, Idiroko Road, Ota, Ogun state. The area of the building is about 23,000sqm and seats over 50,000 people. The building has three wings span with a gallery level linked together at a central point. The design allowed the building shape to spread into three arms which really helped in optimizing the natural energy resource use. Figure 10 shows the aerial view of the Faith Tabernacle Church.

Figure 10. Aerial view showing the Faith Tabernacle (Source: Google.)

4.1.2. Deeper Christian Life Ministries HQ

Figure 11. Aerial view showing the Deeper Christian life Ministry (Source: Google)

Deeper Life Bible Church is a Pentecostal Christian denomination with its international headquarters, Deeper Christian Life Ministry HQ, in Gbagada, Lagos. The shape of the building is a semi-circle with different sectors having different depths. The main bowl seats 30,000 capacity with a basement that houses the 7,500 children's church. The height of the building is about 16-20m spanning three gallery levels with an area of about 7,500sqm. Figure 11 shows the aerial view of the Deeper Life Christian Ministry.

4.1.3. The Rock Cathedral

The Rock Cathedral is a multifunctional church facility that houses The Rock Foundation headquarters as well as the House on the Rock. The building is a Pentagon shaped structure sitting on an area of 7,000 square meters, and it accommodates facilities for worship, education, healthcare among many other initiatives. The main auditorium was designed and built to comfortably seat up to 10,000 people at full capacity and spans up to five floors. Figure 12 shows the front facing façade of The Rock Cathedral.

Figure 12. Front façade of the Rock cathedral (Source: Google)

4.1.4. The Fountain of Life Church HQ

The fountain of Life Church is an 8,000 capacity auditorium, which accommodates facilities like the auditorium, education, healthcare and community development. It is a square shaped building that spans up to five floors sits on an area of 4,500 square meters. Figure 13 shows the front facing façade of The Fountain of Life Church.

Figure 13. The front façade of the Fountain of life church (Source: Google)

Table 3 shows the selected mega-churches and their building characteristics.

4.2. Passive Cooling Strategies Appraisal

In order to enhance the robustness of the appraisal of the passive cooling strategies in the selected mega-churches, the evaluation has been structured into four distinct parts, each focusing on different aspects identified in existing literature. Part A examines the solar shading strategies implemented in the selected mega-churches, considering architectural elements and shading devices. Part B explores natural ventilation strategies, analyzing airflow patterns and ventilation openings. Part C investigates the use of vegetation and landscaping strategies, studying the green vegetations and the water features implemented. Finally, part D shows the Thermal insulation techniques used in the selected mega-churches, looking at the insulation techniques and materials.

4.2.1. Part A: Solar Shading Strategies

Table 4 shows the use of solar shading strategies in the selected mega-churches in Lagos-Ogun megacity.

Table 3. Building Characteristics of the selected mega-churches

SN	Description	Mega-churches			
		Faith Tabernacle	Deeper Christian Life Ministries	The Rock Cathedral	The Fountain of Life Church
1	Building Orientation	Building shape not linear, with three wings facing multiple directions	Longer side facing the east and west	No dominant Alignment due to the non-linear shape	Longer side facing the east and west.
2	Building Shape	Hexagonal center with three wings extending out	Hemispherical with various extruding sectors	Square shaped with a chamfered edge making a pentagon	Rectangular structure
3	Number of Floors	2 floors	6 floors	5 floors	5 floors
4	Capacity	50,000	30,000	10,000	8,000
5	Year built	1999	2018	2013	2014
6	External Wall Finishing	Ceramic wall tiles with stone cladding	Light paint on concrete finish	Light coloured paint with stone cladding	Light coloured paint with stone cladding
7	Walls Construction material.	Hollow Sand-Crete blocks	Hollow Sand-Crete blocks	Hollow Sand-Crete blocks	Hollow Sand-Crete blocks
8	Floor Construction material	Terrazzo floor finish	Marble tiles	Marble tiles	Marble Tiles

Table 4. Solar shading strategies in the selected mega-churches

SN	Solar shading strategies	Selected Mega-churches			
		Faith Tabernacle	Deeper Christian Life Ministries	The Rock Cathedral	The Fountain of Life Church
1	Roof overhangs	—	—	✓	—
2	Façade overhangs	✓	—	✓	—
3	Louvers	—	—	—	—
4	Roof shading	—	—	—	—
5	Shading by trees	✓	—	—	—

The assessment of solar shading strategies in mega-churches revealed notable variations among the selected buildings, as presented in Table 4. For instance, Faith Tabernacle demonstrated an effective employment of solar shading techniques, as shown in Plate 1, incorporating strategically placed trees and vegetation to minimize the direct sunlight impact on the building. The building also had walkways serving as overhangs creating a shade and protection for the exterior walls. Plate 2 shows the walkways acting as shading for the building. On the other hand, the rock cathedral employed a combination of roof overhangs and façade overhangs as effective solar shading measures, as shown in Plate 3. However, it is noteworthy that several other church buildings in the study did not integrate any of the solar shading techniques identified in the existing literature.

Plate 1. The use of trees at the Faith Tabernacle

Plate 2. The façade shading at the Faith Tabernacle

Plate 3. The roof and façade overhangs at the Rock Cathedral

4.2.2. Part B: Natural Ventilation Strategies

Table 5 shows the appraisal of natural ventilation strategies used in the selected mega-churches in Lagos-Ogun megacity.

Table 5. Natural Ventilation strategies in the selected mega-churches

SN	Natural Ventilation strategies	Selected Mega-churches			
		Faith Tabernacle	**Deeper Christian Life Ministries**	**The Rock Cathedral**	**The Fountain of Life Church**
1	Windows	✓	✓	—	✓
2	Clerestory windows	✓	—	—	—
3	Low level windows	—	—	—	—
4	Roof ventilation	—	—	—	—
5	Stack ventilation	—	—	—	—
6	Induced ventilation (solar chimneys and wind towers)	—	—	—	—
7	Ground cooling	—	—	—	—
8	Night ventilation	—	—	—	—

Table 5 presents a comprehensive overview of the natural ventilation strategies employed in the selected mega-churches. As can be seen from the table, The Rock Cathedral did not incorporate any specific natural ventilation measures, resulting in a complete reliance on full air conditioning systems to maintain thermal comfort for the congregants throughout all service periods.

Whereas the Faith Tabernacle, Deeper Christian Life Ministries HQ, and Fountain of Life Church made use of windows to facilitate natural ventilation as part of their passive cooling approach. Although it should be noted that during major services when the churches were at full capacity, the windows were not actively utilized to avoid potential disruptions or discomfort. However, they were made available and utilized during smaller gatherings to effectively reduce cooling loads and enhance natural ventilation.

Notably, the Faith Tabernacle employed clerestory windows, strategically positioned at a higher level, which effectively facilitated the removal of hot air from the interior space, promoting better airflow and improved thermal comfort. Plates 4, 5 and 6 show the use of windows in Faith Tabernacle, Deeper Life Church and the Fountain of Life Church respectively, while Plate 7 shows the absence of the use of windows in the Rock Cathedral.

Plate 4. Faith Terbanacle windows and clerestory windows

Plate 5. Multi-level windows in Deeper Life Christian Ministries HQ

Plate 6. The windows at the Fountain of Life Church

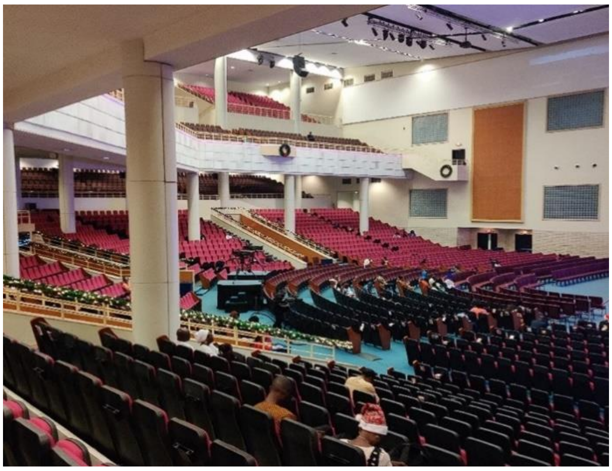

Plate 7. No natural ventilation provision for the Rock Cathedral

4.2.3. Part C: Vegetation and Landscaping Strategies

Table 6 shows the use of vegetation and landscaping strategies in the selected mega-churches in Lagos-Ogun megacity.

Table 6 shows an overview of the presence and utilization of green vegetation in the selected mega-churches. Notably, all of the mega-churches studied incorporated some level of green vegetation within their premises, indicating a recognition of the benefits associated with vegetation in passive cooling strategies.

In particular, The Faith Tabernacle stood out with a notable abundance of vegetation coverage and a variety of trees on its grounds. This deliberate incorporation of greenery not only enhances the aesthetic appeal but also contributes significantly to shading and cooling the surrounding environment. The presence of ample vegetation aids in reducing the intensity of solar radiation, thus mitigating heat gain and promoting a more comfortable microclimate for both the building and its occupants.

Table 6. Vegetation and Landscaping strategies in the selected mega-churches

SN	Vegetation and landscaping strategies	Selected Mega-churches			
		Faith Tabernacle	Deeper Christian Life Ministries	The Rock Cathedral	The Fountain of Life Church
1	Presence of green landscaping	✓	✓	✓	✓
2	Presence of trees	✓	—	—	—
3	Green roofs	—	—	—	—
4	Green walls	—	—	—	—
5	Evaporative cooling (fountains, water bodies)	—	—	✓	—

Furthermore, The Rock Cathedral implemented a water fountain at the entrance as can be seen in Plate 8, which serves as an additional passive cooling feature. The water fountain operates by facilitating evaporative cooling through the evaporation of the surrounding water body. This process contributes to lowering the ambient temperature, creating a more pleasant and refreshing environment near the church building.

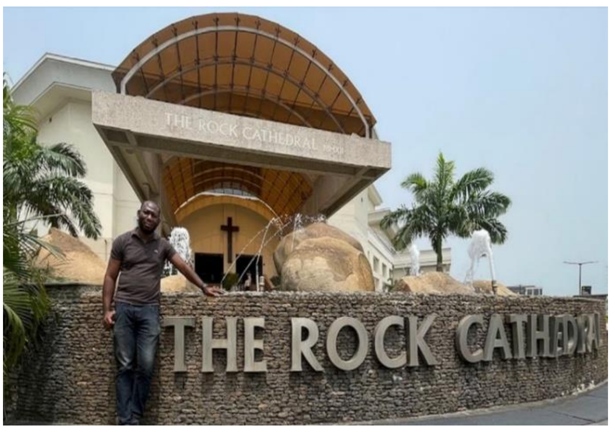

Plate 8. The presence of water fountain in the Rock Cathedral

4.2.4. Part D: Thermal Insulation Techniques

Table 7 shows the appraisal of natural ventilation strategies used in the selected mega-churches in Lagos-Ogun megacity.

Table 7 shows the thermal insulation techniques employed in the selected mega-churches. One notable observation is that all the churches, except for Deeper Christian Life Ministries, utilized stone cladding as a prominent exterior material. This choice of stone cladding showcases its popularity and effectiveness in providing both aesthetic appeal and thermal insulation benefits to the buildings. Additionally, the Faith Tabernacle integrated tinted glazing for the windows and reflective glazing for the curtain walls reducing the impact of glare and heat transfer into the interior of the building. Plate 9 shows the use of stone cladding and ceramic tiled wall in the Faih Tabernacle and plate 10 shows the tinted glazing utilized in the Faith Tabernacle.

Furthermore, it is worth mentioning that all the churches used bright-coloured paints, which can have implications for the thermal performance of the structures. Bright colours have a higher albedo, reflecting a greater proportion of solar radiation and reducing heat absorption compared to darker hues. This choice of bright-coloured paints demonstrates a conscious effort to mitigate heat build-up and contribute to a more comfortable indoor environment.

In terms of design elements, both the Faith Tabernacle and The Rock Cathedral incorporated walkways around the church buildings. These walkways serve as effective buffers, limiting direct heat penetration into the auditorium space. By providing shading and minimizing solar exposure, these walkways contribute to reducing the heat load on the building, enhancing comfort levels for the congregation. Plate 11 and 12 show the use of walkway as buffer spaces at the Rock cathedral and Faith Tabernacle respectively.

Table 7. Thermal Insulation techniques in the selected mega-churches

SN	Thermal insulation techniques	Selected Mega-churches			
		Faith Tabernacle	Deeper Christian Life Ministries	The Rock Cathedral	The Fountain of Life Church
1	Presence of bricks or stone walls	✓	—	✓	✓
2	Wall insulation (cavity walls, aerogels, wood fibre)	—	—	—	—
3	Double or triple glazing	—	—	—	—
4	Tinted / reflective glazing	✓	—	—	—
5	Roof insulation	—	—	—	—
6	Bright wall colours	✓	✓	✓	✓
7	Reflective roof materials	—	—	—	—
8	Buffer Space (Balcony)	✓	—	✓	—

Plate 9. The stone and ceramic wall tiles cladding in Faith Tabernacle

Plate 10. The tinted window glazing in Faith Tabernacle

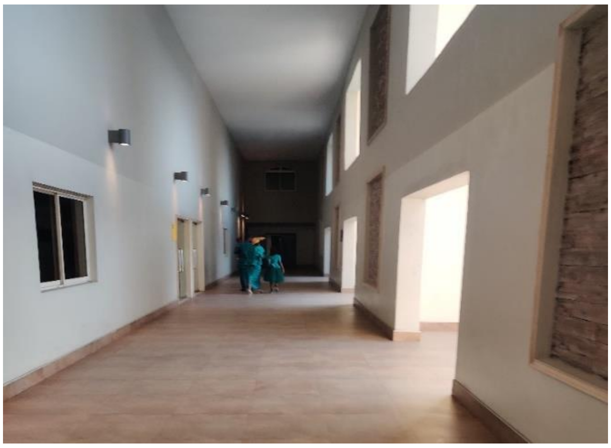

Plate 11. The walkways around the Rock cathedral church

Plate 12. The walkways around the Faith tabernacle church

Overall, the selected mega-churches utilized some of the passive cooling strategies derived from literature, some of which include:

(i) The use of trees, roof and façade overhangs as shading from the sun.
(ii) Presence of windows to promote natural ventilation and air flow in the building.
(iii) Use of landscaping and water features for evaporative cooling.
(iv) Use of stone cladding and buffer spaces for thermal insulation.

These findings underscore the diverse approaches to passive cooling strategies among mega-churches.

From the results, it can be seen that passive cooling was used in all the selected mega-churches, but in different forms and to different extents. However, the Faith tabernacle utilized the most passive cooling strategies across all the categories analyzed in the study. Therefore, an in-depth analysis was done on the Faith Tabernacle to adequately examine the passive cooling strategies utilized in the building.

4.3. Faith Tabernacle Detailed Analysis

Building upon the comparative information acquired from the four selected church buildings, a more detailed study of Faith Tabernacle is presented. Specifically, the assessment of building shape and orientation, evaluation of solar shading and overhangs, measurement of the window-to-wall ratio, and an in-depth analysis of insulation techniques and materials are presented.

4.3.1. Building Shape and Orientation

The Faith Tabernacle is a three-winged structure, with a central hexagon linking all the three wings together. Each wing is a rectangular building with the window openings at the longer sides. The three wings are labelled A, B and C and an orientation analysis was done on the building, as shown in Figure 14.

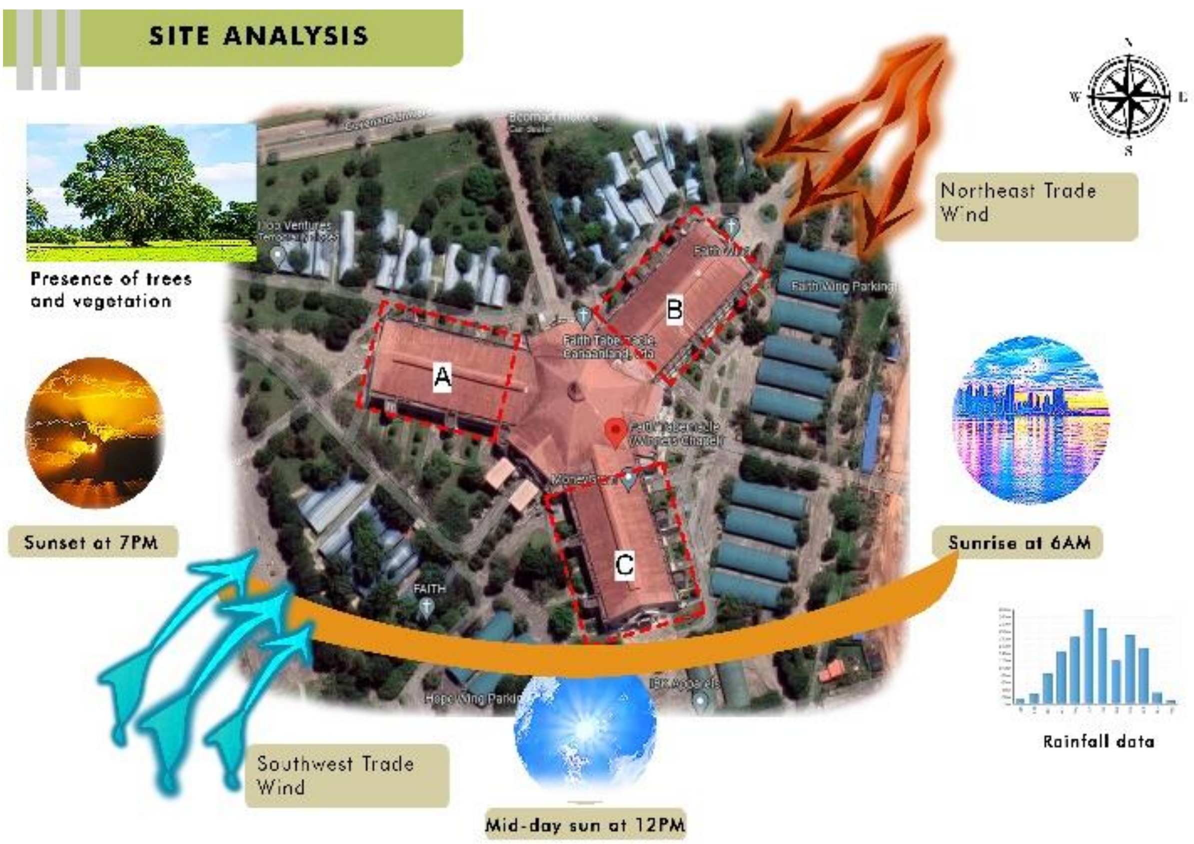

Figure 14. The building orientation analysis of Faith tabernacle (Image Source: Google maps)

Figure 10 shows the building orientation aligned to the north, the sun path, the north-east and south-west wind trades. From the image, we can see the orientation of each of the wings with respect to the wind trade and the sun path. The central hexagon in the building shape linking the three wings has little exposure for natural cooling therefore is being supported with artificial cooling, so the study's main focus was on the three wings.

Wing A has the most optimal orientation, aligning the longer side towards the north and south wing trades and minimizing its exposure to the sun with the shorter side. This reduces the heat gain from the sun and optimizes the natural ventilation wind flow. The orientation of wing B has limited exposure to the north and south wind trade, reducing the natural airflow, while being exposed to the sun along the east and west sun path. Wing C is also exposed to the sun along the east and west sun path increasing its heat gain while also having little exposure to the north and south wind trade.

From the analysis above it can be seen that the most optimal wing in the Faith Tabernacle building is wing A. receiving minimal heat from the sun and getting optimal airflow from the north and south wind trades.

4.3.2. Solar Shading and Overhangs

Solar shading was optimized in several ways in the faith tabernacle, like the use of trees for shading as shown in plate 1, and the use of the walkways around the wings for shading as also shown earlier in plate 12. Both shading strategies are effective for passive cooling. The width of the walkway was measured in relation to the height of the windows to know the extent of protection it offers from sunlight. Figure 15 shows a section through the walkway at different sunlight angles, at 30, 45 and 60 degrees.

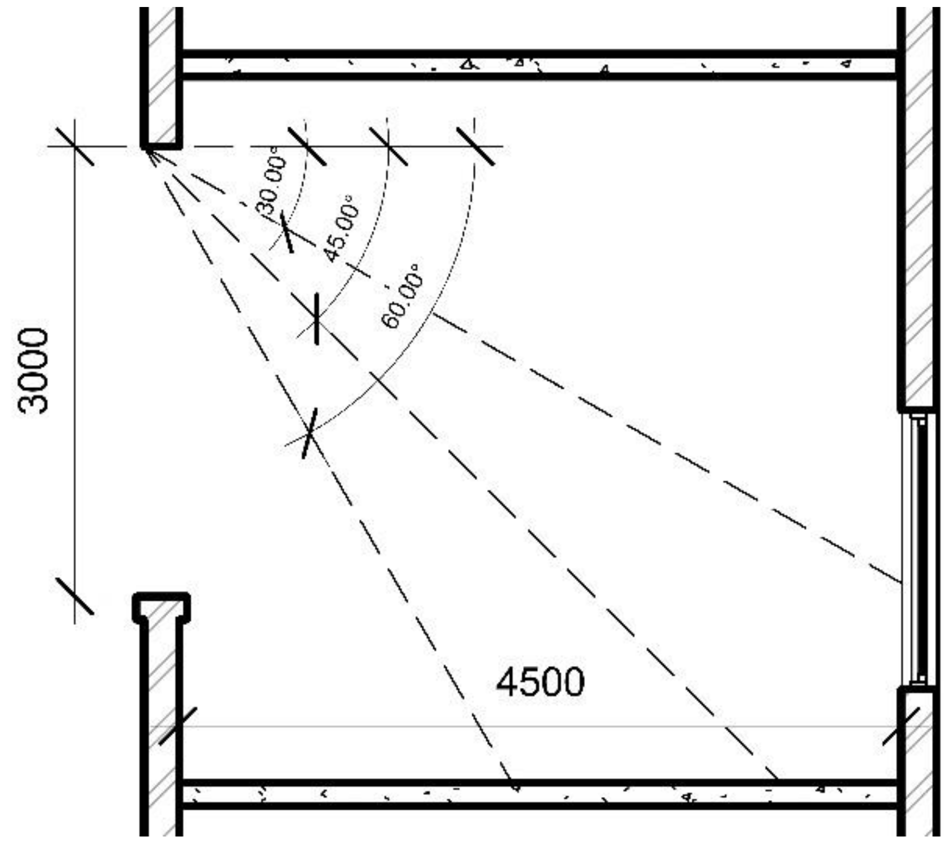

Figure 15. The section through the walkway of Faith tabernacle and sunlight angles. (Source: Author's fieldwork)

As can be seen in Figure 15, only sunlight at the angle of 30 can reach the window level. Low level angles of early morning sunlight are cooler in comparision to higher level angles. From this, we can deduce that the shading provided by the walkways is effective to shade the building from solar heat gain.

4.3.3. Window to Wall Ratio

The Faith Tabernacle majorly used windows along the three wings, it had large windows of 1.8m height by 3.6m width, and clerestory windows of 600mm height by 2.4m width. The study calculated the window to wall ratio for a wing since the three wings are equal and similar in shape. Each wing has 40 main windows and 20 clerestory windows located on the upper floor. Plate 13 shows a rear view from one of the wings.

Plate 13. The wing's rear view in the Faith tabernacle

With each wing's interior spanning 45m by 90m and a headroom of 4.8m for each level of the two floors, the total wall area summed up to 2160m^2. The total main window area was 259.2m^2, while the total clerestory window area was 28.8m^2, making a total of 288m^2. Using these areas, the total window to wall area for one wing was calculated to be 13.33%.

According to the Nigerian Building Energy Efficiency Code (BEEC) [32], the maximum window to wall area ratio should not exceed 20%. This means the faith Tabernacle meets the National Building Energy Efficiency Code (BEEC) standard for window to wall area ratio.

4.3.4. Thermal Insulation Techniques and Materials

The faith tabernacle used a combination of thermal insulation materials and thermal insulation technique. The exterior walls are finished with ceramic wall tiles and stone cladding as can be seen in plate 9. Although the aim of this was for aesthetic purposes, it contributes to the thermal insulation of the exterior walls. The ceiling was finished with Wooden sheets and PVC, which has low insulation properties and the floor was a terrazzo floor finish. The most effective thermal insulation technique used in the church was the use of walkways as a buffer as can be seen in plate 12. All these contribute together to improve the thermal insulation of the building.

4.4. Discussions

The evaluation of passive cooling strategies in mega-churches yielded several key findings regarding the implementation of passive cooling strategies in mega-churches.

The study divided the passive strategies gleaned from literature into four different categories, which are solar shading, natural ventilation, vegetation and landscaping, and thermal insulation and analyzed the selected mega-churches respectively.

Solar shading is a crucial factor in mitigating heat gain [2]. While some mega-churches incorporated effective shading techniques such as trees and vegetation (as seen in the Faith Tabernacle) or roof and façade overhangs (as observed in The Rock Cathedral), it was discovered that Deeper life Christian ministries and the Fountain of Life Church did not integrate any of the identified solar shading strategies. This indicates a potential area for improvement and highlights the importance of raising awareness and promoting the implementation of effective shading measures.

The adoption of natural ventilation strategies varied among the mega-churches. While the Faith Tabernacle, Deeper Christian Life Ministries HQ, and Fountain of Life Church incorporated windows to facilitate natural airflow, it was found that these windows were not actively utilized during major services at full capacity, possibly to avoid disruptions. Nevertheless, the incorporation of clerestory windows (in the case of Faith Tabernacle) demonstrated an understanding of the benefits of natural ventilation in improving indoor air quality and reducing cooling loads [14] [15].

The presence of green vegetation was a common feature in all the studied mega-churches. The extensive vegetation coverage in the Faith Tabernacle played a vital role in shading and cooling the surrounding environment. Additionally, The Rock Cathedral's use of a water fountain at the entrance provided evaporative cooling through the water body surrounding the building. These findings underscore the recognition of the positive impact of vegetation and water features in creating a comfortable and sustainable microclimate [2].

The choice of building materials and design elements also influenced passive cooling strategies. Stone cladding was a popular selection among the mega-churches, offering both thermal insulation properties and aesthetic appeal. Bright-coloured paints were employed, reflecting a conscious effort to reduce heat absorption by reflecting a greater portion of solar radiation. Furthermore, the inclusion of walkways around the church buildings (as observed in the Faith Tabernacle and The Rock Cathedral) acted as buffers, minimizing direct heat penetration into the auditorium spaces [27].

Despite the presence of all the aforementioned passive cooling strategies present in the selected mega-churches, the churches still relied on artificial cooling during major operation hours. It can be inferred that the passive strategies used were not adequate in meeting the needs of the large congregation of the churches. This could be as a result of the inadequate application or combination of different cooling strategies that address the climatic context of the church building. The incorporation of other key strategies obtained from literature can help in reducing cooling demand, such as stack ventilation, ground cooling, triple glazing, façade and roof shading. These strategies would be beneficial in providing comfort in large spaces as in the case of mega-churches. In addition, optimizing the use of passive cooling strategies helps in saving the cost of running on artificial cooling while promoting environmental sustainability.

5. Conclusions and Recommendations

The goal of this study was to evaluate the application of passive cooling strategies used to achieve environmental sustainability in four selected megachurches in Lagos-Ogun Megacity, Nigeria. In order to fulfil the study's goal, two objectives were formulated. The first objective was to identify the passive cooling strategies used in buildings; this was achieved using literature review. From the literature review four major aspects of passive cooling strategies were found, which were Solar shading, natural ventilation, green vegetation and thermal mass. The second objective was to examine the extent to which selected mega-churches applied the identified passive cooling strategies, an observation guide was employed to examine the passive cooling strategies utilized in the selected mega-churches. The evaluation of passive cooling strategies in mega-churches revealed that some mega-churches effectively incorporated some of these strategies. Others had room for improvement. The study found out that none of the selected mega-churches were able to meet the needs of the users through the adopted passive cooling strategies found in their respective buildings. The mega-churches relied heavily on artificial cooling during their times of operation. The faith Tabernacle had the highest level of adoption, despite that, it was still inadequate to meet the capacity needs. Some of the other key strategies were not utilized in any of the buildings. For example, the use of stack ventilation, triple glazing and ground cooling. Enhancing solar shading techniques, promoting natural ventilation through operable windows, and prioritizing the integration of green spaces and water features are major recommendations for mega-churches seeking to optimize passive cooling.

Based on the study findings, the following are the suggested recommendations for potential improvements in the use of passive cooling strategies in megachurches towards achieving environmental sustainability.

(i) There is a need to create awareness on the benefits of passive cooling in megachurches and the negative impacts of the excessive use of artificial cooling in church buildings.
(ii) From the early stage of the design. a holistic approach should be adopted, integrating multiple passive cooling strategies tailored to the specific context and climate.
(iii) Thermal simulations can be carried out to examine the effectiveness of the passive cooling strategies utilized.
(iv) Artificial cooling can be used but must not be the major cooling source but should be used to support the passive cooling strategies.
(v) Planning authorities should enforce the use of passive cooling in mega churches in order to ensure environmental sustainability being promoted.

Conflict of Interest

The authors declare no conflict of interest.

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