





Climate Adaptations of Religious Buildings in Enugu State, Nigeria

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Abstract	Article History
<p>This study investigated climate-responsive design strategies employed in Orthodox church buildings within Enugu Metropolis, Nigeria, a region characterised by a temperate-humid climate with distinct wet and dry seasons, high temperatures, and intense sunshine. These climatic conditions pose significant challenges for building design, often leading to excessive heat gain and humidity issues. Climate-adaptive architecture, which integrates natural climatic factors into building design, offers a potential solution by minimising reliance on mechanical cooling and promoting indoor comfort. Focusing on religious buildings, which often accommodate large congregations and consume substantial energy for climate control, this research aimed to identify and evaluate effective design approaches for addressing local climate requirements and enhancing climate resilience as well as proffer recommendations for future building projects. A survey design was employed, utilizing observation schedules and questionnaires to collect data from six selected churches within Enugu Metropolis, with a minimum of a 1000-person seating capacity. The findings revealed that while all surveyed churches demonstrate a good response to the tropical climate, the Cathedral Church of Good Shepherd exhibits the highest performance across various parameters, including thermal comfort, natural airflow and air quality, effective shading from the Sun, and visual appeal through landscape elements and water conservation. The study concluded by providing recommendations for enhancing climate responsiveness in future church building designs in Enugu and similar tropical climates such as optimal building orientation, natural ventilation, appropriate material selection, shading devices, rainwater harvesting, and integrated landscaping.</p> <p>Keywords: <i>Climate-Responsive Architecture; Tropical Climate Building Design; Church Architecture; Passive Cooling Strategies; Enugu, Nigeria</i></p>	<p>Received: 21 Feb 2025 Accepted: 28 Feb 2025 Published: 14 Mar 2025</p>  <p>Scan QR code to view*</p> <p>License: CC BY 4.0*</p>  <p>Open Access article</p>
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1. Introduction

According to the Bioclimatic chart of climate classification, Enugu, Nigeria, falls within the temperate-humid zone and features a wet and dry climate, characterized by high temperatures, seasonal rainfall, intense sunshine, and long and varied daylight hours (Mobolade & Pourvahidi, 2020; Nsa et al., 2021; Weather Atlas, 2024). This climatic condition typically results in minimal temperature variation between the wet and dry seasons but intense and persistent heat and moisture (*ibid*). Such environmental factors pose substantial challenges for building design and functionality. Buildings in this climatic region often struggle with excessive heat gain, increased humidity, and moisture-related issues such as mould and deterioration, all of which can impact the comfort and sustainability of the indoor environment (Echeta et al., 2023b; Munonye et al., 2023).

To address these challenges, climate-adaptive architecture has become a crucial approach in the design of buildings with

minimal environmental footprints. This design philosophy integrates natural climatic factors into architectural design to improve indoor comfort and reduce the need for mechanical cooling systems, employing such strategies as shading devices, natural ventilation, and thermal mass to regulate indoor temperatures and minimize energy consumption, given the extensive hours man spends within the built environment (Echeta et al., 2023a; Ogunsote & Prucnal-Ogunsote, 2002; Munonye et al., 2021; Jonas & Basil, 2022). This is particularly relevant in Enugu, where innovative design solutions are necessary, given the state's unique environmental characteristics of being in a transitional zone between the tropical rainforest and derived savannah (Nsa et al., 2021) and poor power supply to sustain mechanical means of ventilation (Umeora & Onwuzuligbo, 2021).

Religious buildings are a major landmark in any environment, accommodating a vast number of persons in worship at given intervals. However, with the need to accommodate a crowd for

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worship in comfort, comes the challenge of expending energy to regulate the indoor environment. Consequently, such large energy-demanding buildings are expected to employ passive means by being responsive to the climate of the region. Previous studies have highlighted the dependence of religious buildings on mechanical means for regulating indoor environment in hot-humid and Mediterranean climates (Ezema et al., 2023; Vella, 2020), and the increased risk of damage to internal fixtures and fittings in naturally ventilated church interiors in cold climates. Despite the importance of climate-responsive architecture, there is limited research on how these strategies are applied in religious buildings in Enugu.

The study therefore aims to investigate design strategies used in these buildings within the state, to identify effective approaches for addressing local climate requirements, and provide recommendations for enhancing climate resilience in future projects in the state, and in regions with similar climate conditions. Specifically, the study will: (1) identify design strategies for religious buildings, particularly Orthodox churches that meet the climatic demands of the region; (2) evaluate the use of and effectiveness of these strategies in addressing the challenges posed by the tropical climate of Enugu State, Nigeria; (3) proffer recommendations for the climate responsiveness of the buildings.

Study Area

The study area, as shown in Figure 1, is Enugu Metropolis, comprising Enugu-South, Enugu-North, and Enugu East local government areas, in Enugu State. Enugu State is in the southeastern part of Nigeria and has 17 Local Government Areas. Enugu city/metropolis has an area coverage of 113km²-an estimated population of 876,000 and a population density of about 427.6 persons per square kilometre (Macrotrends, n.d.; Okoye et al., 2018). Geographically, Enugu metropolis is located at latitude 6° 25'N and 7° 03'N of the equator and between 7° 25'E and 8° 19'E of the Greenwich Meridian. The state is characterized by hills, peaking at an elevation of about 1000m above mean sea level (Chukwu, 2015, as cited in Okoye et al., 2018), accounting for the slight difference in climatic conditions between the state and other Southeastern states of Nigeria.

Literature Review

Climate-responsive design refers to architectural and urban design strategies that take into account the local climate of a geographical area to minimize energy consumption and enhance the comfort of the building's occupants (Adedayo et al., 2013; Kabiru, 2011). This approach involves the use of natural resources, such as sunlight, wind, and thermal mass, to reduce reliance on mechanical heating, cooling, and lighting systems. According to Olgyay (2015), as cited in Kabiru (2011), the goal is to create buildings that are both energy-efficient and comfortable, while also being sustainable and environmentally friendly. Furthermore, Turner (2003) in Kabiru (2011), opines that climate-responsive designs stem from vernacular architecture that employs techniques and features that are adapted to the cultural context and patterns of the region.

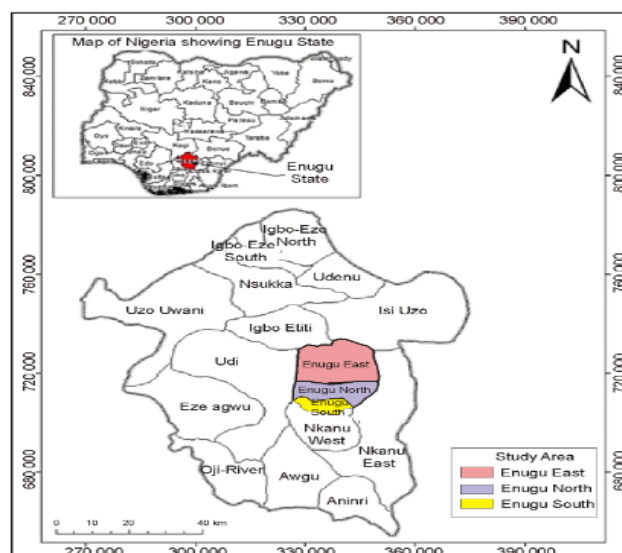


Figure 1: The study area, Enugu Metropolis in Enugu State, Nigeria (Source: Ejikeme et al., 2023)

Climate Overview of Enugu

The climatic condition of a given area is one of the most important factors that define the formation of building design with sensitivity to environmental conditions. Enugu metropolis located in Enugu state, south-eastern Nigeria, experiences a tropical climate characterized by high temperature, high humidity, and distinct wet and dry seasons (Weather Atlas, 2024). This climate has significant implications for Architecture/Building, agriculture, water resources, and other aspects of life in the region, and are characterized by:

Temperature: Enugu exhibits a warm climate throughout the year, with average temperatures ranging from 24°C to 28°C (75°F to 82°F). The temperature tends to be higher during the dry season (November to March), often reaching between 30°C and 35°C (86°F to 95°F) due to the influence of the harmattan winds, which bring dry and hot air from the Sahara Desert. During the wet season (April to October), temperatures are relatively moderate, with average highs of 24°C to 28°C (75°F to 82°F) (Weather Atlas, 2024; Ejikeme et al., 2023).

Humidity: According to Okoro et al. (2022), humidity in Enugu is typically high during the wet season, with levels often exceeding 80%. This high humidity is attributed to the abundant rainfall and moist air brought by the southwest monsoon winds. Conversely, humidity levels drop significantly during the dry season due to the harmattan, which can reduce relative humidity to below 40%. The contrast between the humid wet season and the dry harmattan period is a significant feature of Enugu's climate, influencing the thermal comfort of building occupants throughout the year.

Rainfall: Onyia (2017) analysed the rainfall pattern of Enugu and found a seasonal pattern, with the wet season bringing substantial rainfall from April to October. Annual rainfall averages between 1,500 mm and 2,000 mm (59 inches to 79 inches). The peak rainfall typically occurs in July and September, with monthly totals reaching up to 300 mm (11.8inches) during these months. In contrast, the dry season experiences minimal rainfall, with the months from November to March receiving significantly lower amounts, contributing to drier conditions.

Orthodox Church Buildings in Enugu Metropolis

Orthodox Church buildings are integral to the cultural and religious landmarks that reflect the traditions and architectural heritage of the Christian community. The architecture of these church buildings is often an attempt to blend a typical building typology into a local climatic and cultural context, thus, striking a balance between form, function and local identity. Thus, in terms of climate differences, Enugu's tropical climate presents challenges for traditional Orthodox architecture, which originated in cooler, drier regions. Orthodox church buildings, therefore, may not fully incorporate climate-responsive design principles, leading to issues like inadequate ventilation, excessive heat, and energy inefficiency.

As in other parts of Nigeria, Orthodox Christianity in Enugu is represented by several branches. These churches, which adhere to ancient Christian liturgies and doctrines, have established a presence in Enugu, serving the spiritual needs of their congregations. These churches share common roots in early Christian traditions but have different theological and liturgical practices that distinguish them from one another. The primary Orthodox Churches in Enugu include:

1. Roman Catholic Churches e.g., St. Mulumba Church, UNEC.
2. Anglican Churches e.g., St. Matthew's Anglican Church, New Haven, Enugu
3. Presbyterian Church, such as, the Presbyterian Church of Nigeria, Enugu Parish, Uwani, Enugu.
4. Methodist Church, such as, the Wesley Cathedral Methodist Church, Uwani, Enugu.

Climate-Responsiveness of Church Design

The following recommendations for tropical building designs were drawn from Erebor et al. (2021), Bulbaai and Halman (2021), Gupta and Deb (2023), Jonas et al. (2022), Rattanongphisat and Rordprapat (2014) and Umeora et al. (2023), and are applicable in public spaces such as church buildings.

Orientation and Building Layout: 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 Enugu, aligning the building along the east-west axis can reduce heat gain from the low-angle sun in the morning and evening.

Natural Ventilation: Natural ventilation is essential for preserving indoor comfort in Enugu's warm and humid climate. Designing religious buildings with large openings, strategically placed windows, and cross-ventilation paths can harness prevailing winds to cool the interior spaces.

Shading Devices: By shielding the building from direct sunshine, shading devices/techniques such as fin walls, pergolas, overhangs, and louvers help lower heat gain within such facilities.

Integrated renewable Energy: Renewable energy is a crucial component of climate-responsive architecture, particularly in tropical regions where high temperatures and humidity levels demand significant energy for cooling and ventilation. In tropical climates, where solar radiation is intense and

consistent throughout the year, buildings should be designed to minimize energy consumption while maintaining the comfort of users.

Proper Landscaping: By integrating natural landscaping elements into the design, religious institutions can create spaces that reflect their commitment to environmental stewardship, offer a serene environment for worship and contemplation, and serve as a living example of sustainable practices. Thoughtfully designed landscapes around religious spaces can serve multiple functions, from improving energy efficiency to fostering a deeper connection with nature as the case may be.

Material Selection and Insulation: The choice of building materials is crucial in climate-responsive design. In Enugu, materials that can withstand high humidity and rainfall, while also providing insulation against heat, are ideal. Local materials such as clay bricks, rubble stones etc. which have been traditionally used in the region, offer good thermal properties and can reduce the environmental impact by minimizing transportation needs.

Reflective Roofing: Using reflective materials for roofing, such as light-coloured tiles or metal sheets, can significantly reduce heat absorption. Green roofs, where feasible, can provide additional insulation and contribute to the building's aesthetic appeal.

Acoustics: The open and airy design of religious buildings in tropical climates, while beneficial for ventilation, can pose challenges for acoustics. The use of sound-absorbing materials like acoustic boards as interior wall finishes, acoustic ceilings, acoustic foam and strategic placement of walls and barriers is essential to ensure clear sound transmission during meetings/services.

Flood-Resilient Design: Elevated foundations and the use of water-resistant materials can protect religious buildings from potential flooding, a risk that may increase with climate change in Enugu.

Water Management and Rainwater Harvesting: Roofs can be designed to collect rainwater, which can then be stored and used for non-potable purposes such as irrigation and sanitation. This strategy not only conserves water but also reduces the load on local water supply systems.

2. Materials and Methods

The study employed a survey design. Primary data was collected using an observation schedule and a questionnaire. The research population were Orthodox Church buildings in Enugu metropolis, given the prevalence of these churches, in contrast to the almost non-existent presence of Islamic religious buildings in the area. Again, these churches tend to follow a particular pattern in the design of buildings for worship. The inclusion criterion for the sampled church building is having a capacity of at least 1000 persons. The included churches are shown in Table 1. A convenient number of 50 persons from each sampled church building were randomly selected as the study respondents, having met these criteria: (1) is an adult; (2) actively worships in the church branch so sampled for a minimum of two seasons (3) understands the English language without any help.

Table 1: Selected Church Buildings in Enugu to be Studied

Selected Church Buildings	Capacity	Sample Size
Cathedral Church of Good Shepherd, Enugu	3000	50
Holy Trinity Catholic Church, Enugu	3000	50
St. Mulumba Catholic Chaplaincy, UNEC	1000	50
Chapel of Redemption, Anglican Church, UNEC.	1000	50
Christ Redemption Anglican Church, UNEC	2000	50
St. Anthony’s Parish, Ogui New Layout, Enugu.	2000	50

The instruments used to collect primary data for this study were an observation schedule and a structured questionnaire. While the former tool was used to observe the design attributes of the sampled church buildings, the latter was used to rank the respondents’ assessment of the performance of these design attributes.

3. Results and Discussion

Objective 1: To identify design attributes that meet the climatic demands of Enugu Urban

Table 2 presents the summary of the design attributes of the understudied church buildings, indicating the presence, or otherwise of specific features.

Table 2: Design Attributes of the cases studied

S/N	NAME OF CHURCH	Orientation	Natural Ventilation	Sun-shading devices	Roofing	Landscaping	Rainwater Harvesting	Building Materials
1.	St. Anthony’s Parish, Ogui New Layout, Enugu.	X	X	X	V	X	X	V
2.	Chapel of Redemption Anglican Church, UNEC, Enugu,	V	V	V	V	V	X	V
3.	Christ Redemption Anglican Church, Enugu.	V	V	V	V	V	X	V
4.	Holy Trinity Catholic Church, Enugu	V	V	V	V	X	X	V
5.	ST. Mulumba Catholic Chaplaincy, UNEC, Enugu.	V	V	V	V	V	X	V
6.	Cathedral Church of Good Shepherd Enugu.	V	V	V	V	V	V	V

1. Orientation:

Churches marked with “V” in this column had buildings oriented with the longer side moving along the North-West South-Eastern cardinal axis. This allowed proper ventilation improving thermal comfort, while the churches marked “X” did not.

2. Natural Ventilation:

Churches marked with “V” had windows in place which aided natural ventilation which improved indoor air quality, while churches marked “X” didn’t.

3. Sun-shading Devices:

Churches marked with “V” were constructed with adequate roof eave distances and window hoods and fin walls were also used which aided with the control of solar radiation intake to the building, while churches marked “X” didn’t.

4. Roofing:

Churches marked with “V” were constructed with adequate pitch angles and eave projections.

5. Landscaping:

Churches marked with “V” provided adequate site landscaping which includes trees, grass and shrubs which enhance aesthetic appeal, serve as noise buffers and cool the ambient environment, while churches marked “X” didn’t.

6. Rainwater Harvesting:

Churches marked with “V” provided an on-site rainwater harvesting measure, while churches marked “X” didn’t.

7. Building Materials:

Churches marked with “V” were constructed with reinforced concrete frame structures with sandcrete hollow block walls. Objective 2: To evaluate the effectiveness of these design attributes in addressing the challenges posed by the tropical climate of Enugu state.

An experiential assessment of the performance of the building was carried out for each sampled church under specific indicators. The ranking was on a Likert scale of 1-5 (1 = very dissatisfied; 2 = fairly dissatisfied; 3 = neutral; 4 = fairly satisfied; 5 = very satisfied), which were averaged and presented in Table 3:

Table 3: Performance rating of sampled church buildings

Churches	Thermal Comfort	Natural airflow and air quality	Effective shading from the Sun	Acoustics and speech clarity	Visual appeal through landscape	Water Conservation	Average Rating
Cathedral Church of Good Shepherd, Enugu	4.80	4.80	5.0	5.0	4.90	4.40	4.81
Holy Trinity Catholic Church, Enugu	4.60	4.40	4.30	4.60	4.50	4.30	4.45
St. Mulumba Catholic Church, UNEC	4.30	4.30	4.05	4.70	4.50	4.30	4.35
Chapel of Redemption, Anglican Church, UNEC.	4.30	4.60	4.25	4.70	4.40	4.30	4.42
Christ Redemption Church, UNEC	4.50	4.60	4.25	4.60	4.50	4.50	4.49
St. Anthony's Catholic Church, Enugu	4.30	4.25	4.05	4.70	4.40	4.30	4.33

The study's findings revealed that the Cathedral Church of Good Shepherd stands out with the highest ratings across various climatic response parameters. This church consistently outperformed others in areas such as thermal comfort, natural airflow and air quality, effective shading from the sun, acoustics, landscape, and water conservation. The study found that, in general, 100% of the churches surveyed demonstrate a good response to the tropical climate. The buildings

collectively manage to maintain a balance between thermal comfort, energy efficiency, and sustainability. These findings highlight the effectiveness of the climate-responsive strategies employed in Orthodox church buildings in Enugu, showcasing a positive trend towards environmentally conscious design in the region.

4. Conclusion and Recommendation

The research analysed climate-responsive design strategies in seven church buildings in Enugu, with a focus on their effectiveness in addressing the tropical climate. The study's findings revealed that the Cathedral Church of Good Shepherd (Chapel) stands out with the highest ratings across various climatic response parameters. This church consistently outperformed others in areas such as thermal comfort, natural ventilation, air quality, solar radiation management, acoustics, energy efficiency, and water conservation. The study found that 100% of the churches surveyed demonstrate a good response to the tropical climate. The buildings collectively manage to maintain a balance between thermal comfort, energy efficiency, and sustainability.

Based on the findings from the analysis of church buildings in Enugu, several recommendations can be made to enhance their climate responsiveness, promote sustainable building practices and reduce energy and material costs:

- **Building Orientation and Layout:** It is recommended that churches are aligned along the east-west axis to minimize direct sunlight exposure.
- **Natural Ventilation:** Churches should have high ceilings to allow hot air to rise and keep lower spaces cooler. High-level openable windows should be

accessible via a small gallery to achieve stack-effect ventilation.

- **Material Selection:** Thick masonry walls like stone-faced masonry walls with high thermal mass are recommended to moderate indoor temperatures.
- **Roof Design:** Implementing steeply pitched roofs for efficient rainwater drainage and adding roof overhangs to protect walls from direct sunlight and rain.
- **Shading and Sun Protection:** The use of fin walls and verandas is recommended for sun shading and strategic landscaping with trees and shrubs for natural cooling.
- **Water Management:** It is recommended that rainwater collector systems are attached to the roofs to conserve water and efficient drainage systems to handle heavy rains.
- **Acoustic Considerations:** High ceilings and sound absorbent ceilings materials like wood are recommended to achieve good acoustics
- **Landscape:** soft landscapes are recommended to provide natural shading around the building and visual appeal.

Competing interests

The authors declare no competing interests.

Author contributions

All authors contributed to the development of this work. They have all read and approved the final manuscript.

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