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EXPLORING ENERGY EFFICIENCY IN ROMAN CATHOLIC CATHEDRALS

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ABSTRACT
Lots of Existing Roman Catholic Cathedrals in Nigeria lack basic energy-efficiency requirements. It is evident that the continued clamor for the construction of energy-efficient Roman Catholic cathedrals is a result of the prevailing energy-consuming design and service patterns of Nigerian buildings and the energy consuming behavioral patterns of Nigeria's energy users. The design and construction of energy-efficient buildings often comprise of measures to mitigate energy consumption. These measures include several design techniques which can enhance the energy efficiency of a Roman Catholic cathedral if applied. This research is explorative and review of existing literature was utilized as a means of data collection. The key findings in this research are passive building applications, evaporative cooling system and renewable energy sources.

1.0. Introduction

The term cathedral refers to the principal church of a diocese; in other words, a Roman Catholic cathedral is the principal or chief church of a Roman Catholic diocese – a structure where the throne of the bishop is located. (Catholic University of America, 2003). As a church building, a Roman Catholic cathedral serves as a place where the holy liturgy is celebrated by the users which include the gathered congregation and the clergy (Catholic University of America, 2003). The Catholic University of America (2003) further discussed –in the Encyclopedia of the Catholic Church – that ecclesiastical administration is needed to unite the people of God and to ensure sound teachings on faith and doctrine for the whole Church. Consequently, the Roman Catholic cathedral serves as a means to proclaim the word of God and administer the holy sacraments to the people of God. Each of these purposes served by the Roman Catholic cathedral has its own methods and strategies for achieving its purpose. The Catholic diocese typically relies on its cathedral – the bishop's church – for the purposes of pontifical administration and the celebration of the sacred liturgy (Catholic University of America, 2003). In addition to ecclesiastical purposes such as the celebration of the holy mass, ordination and consecration of the clergy, veneration and devotions, cathedrals can also be used as a sanctuary for the displaced and persecuted especially in times of war and natural disaster (Bennet et al, 2016).

In the view of McDannel (1995) the design of Catholic cathedrals have been evolving over the years to adapt to ecclesiastical, cultural and environmental demands of the users; therefore, across the globe, the demand for optimum indoor air condition in Catholic cathedrals can affect the choice of building materials and the technique of design and construction of the cathedral. According to Bamisile et al. (2020), Nigeria is also having challenges in meeting the energy demands of its ever-increasing population, especially in the aspect of electricity; this causes the need for energy-efficient methods of building designs and construction of Catholic cathedrals in order to reduce energy consumption and save cost. Cathedrals have also played a crucial role in the world of Catholicism as the mother church and symbol of authority and administration of every diocese and most important information regarding the administration of the people of God under the jurisdiction of the bishop of the diocese are disseminated from the cathedral (Catholic University of America, 2003). Energy-efficiency is the current trend and according to the Chattered Institute of Building Services Engineers (2004), there is need to improve the energy performance of buildings, reduce $C0_2$ emission and save cost. Just like every other buildings, Roman Catholic cathedrals are expected to move with this current trend of energy efficiency through design and choice of building materials to a significant extent to which effect the ultimate goal of every 21st century architect ought to be to plan with effective energy-efficient considerations in mind, in order to give the people of God the best optimum in-door air quality for the respective ecclesiastical activities in order to build cathedrals that can perform in the present and also adapt in the future.

According to Mukhtar et al. (2021) alternative practices are needed to complement the existing insufficient energy systems of Nigeria and this can be done in no better way other than through the exploration of all available energy efficiency options. Just like every other buildings there is a need to pay greater attention towards improving energy performance of Roman Catholic cathedrals in order to reduce CO_2 emission and save their operational cost. This study is intended to explore and assess the prevailing energy efficiency challenges on the part of the end-users in Nigeria. The attention is on the various ways through which energy efficiency can be achieved and improved in the specified Roman Catholic Cathedral. Factors influencing energy efficiency such as sustainable systems of achieving lighting, ventilation and air-conditioning, through sustainable human behaviors and applications geared towards lowering energy consumption in such facilities, shall be discussed in this study.

The aim of this journal is to throw some light on possible the application of energy efficiency in Roman Catholic cathedrals and discuss means to achieve and improve energy efficiency in it and the objectives of this research seek to ensure that there is no visual obstruction between the nave and the sanctuary, ensure the cathedral is properly planned and laid out on the site, ensure complete integration of all the component spaces of the cathedral, and achieve a design that reflects the concept of cathedral. Little research so far has been conducted on architectural solutions for increasing the energy efficiency of Roman Catholic cathedrals especially in Nigeria. It is for this reason that this study sought to explore and evaluate sustainable systems of building design, service applications and human behavioral patterns to make this facility energy-efficient by identifying how to explore energy-efficiency in the building type. This study will help to design a functional energy-efficient cathedral which reflects the image of a Roman Catholic cathedral and most importantly, will bring to its readers, the considerations and strategies needed for the design of an energy-efficient Roman Catholic cathedral.

2.0. The Role of Roman Catholic Cathedrals

The principal role of a Cathedral is to serve as the principal church of a Roman Catholic diocese as well as the seat of the diocesan administration of the bishop while also serving as a means for the liturgical celebrations of the Church (Catholic University of America, 2003). Inasmuch as a Roman Catholic cathedral has as its principal role to provide means for the celebration of the divine liturgy, in special circumstances, cathedrals or churches could serve other purposes. Consequently, Bennet et al. (2016) in their view, discussed that in times of crises or war, Catholic facilities especially, churches usually serve as sanctuaries to the displaced and persecuted. Accordingly, this role is discussed by the Catholic Church Canadian Canon Law Society (1997); to serve as a proper means for the delivery of services of charity and sacred apostolate, especially to the poor and the needy, a role which is supplementary to the principal role of churches, which is to provide the Church with proper means for the celebration of divine worship.

3.0. Architectural Models of the Roman Catholic Church Buildings

Up till this moment, the Catholic Church has not yet adopted any specific architectural style for her church buildings, but the Church has nevertheless, employed architectural styles from every period, while maintaining the natural characteristics and conditions of peoples, as well as the ecclesiastical needs of every right of the Church (McDannel, 1995). Nevertheless, the Catholic Church (1994) has defined two basic models to describe her church buildings. The Catholic Church (1994) further discussed that the first is that of the *"domus Dei",* or house of God. This system of description was predominant prior to and during the First Vatican Council of 1869. It draws its inspiration from the Jewish temple tradition and intends to emphasize the holiness and sacredness of God's presence in the church, especially through the Blessed Sacrament, with respect to the imperfection of human beings - the gathered Christian assembly (the Catholic Church, 1994).

The second model is the "Dominus ecclesia", or the people of God which came with the Second Vatican Council of 1963. This method of description emphasizes that God dwells among his people through Christ, the center of the divine worship (Bishops' Committee on the liturgy, 1978). Church designs, which result from this trend often have a round sitting formation, with the altar placed at or near the center of the congregation, such that emphasis of the design is the altar of sacrifice (Bess, 2003a). The *"Dominus ecclesia"* model calls to mind that Christ has saved his Church, and through this salvation granted the Church by Christ, she has been purified and justified through faith to approach the Father without fear, but with love and confidence. The *"Dominus ecclesia"* model integrates the gathered assembly with the liturgical sacrifice on the altar, brings them closer to the spirit of the mass, and arouses the enthusiasm of active participation of all the faithful during the mass. Another optional way in which the Dominus ecclesia model may be architecturally expressed is through the use of a lowered ceiling height, in order to bring a sense of closeness to the gathered assembly, in contrast with that of the lofty spaces provided by high vaulted ceilings of the Dominus Dei models (Bess, 2003b). This philosophy influenced the round sitting formation of modern Catholic churches, tending to mimic the round-the-table sitting formation of the Last Supper, where Jesus sat around a table with his disciples.

4.0. The Concept of Energy Efficiency

Jones (2004) defined energy efficiency as the practice of providing the required internal environment and services with minimum energy use in a cost effective and environmentally friendly manner. A building which satisfies this demand is an energy-efficient building. Energy-efficient applications conserve energy, discourage energy wastage, save cost, and make the building envelope friendly with the environment. In application to the eco-friendly management of the natural resources utilized in our homes, towns, and cities, energy efficiency is an important factor which cuts across principally, aspects of economics, as well as the demands of the society (Hermoso-Orzaez & Gago-Calderon, 2020). Energy efficiency provides a good approach towards curbing and managing the energy deficiencies of Nigerian buildings, including Roman Catholic Cathedrals and changing the ugly narrative to the positive because, from the opinion of Filipin (2007), energy efficiency promotes the use of environmentally-sensitive design approaches, the improvement of the church buildings, the changing of energy consumption systems among the users, and the application of renewable energy. Ali et al. (2020) opines that the major aim of every nation is to achieve sustainability in development and consequently, in the view of Gillingham et al. (2009), in order to achieve sustainable energy policy goals as well as a reduction in greenhouse gases emission, energy efficiency has become a key factor. The goal of energy efficiency design of Roman Catholic cathedrals is to achieve higher energy performance of the buildings, using little energy in accordance with the opinion of Jones (2004), who defined energy efficiency as the practice of providing the required internal environment and services with minimum energy use in a cost effective and environmentally-friendly manner.

5.0. Some Energy-Consuming Practices Prevalent in Nigeria

In the opinion of Filipin (2007), energy efficiency ought to promote the use of environmentally-sensitive design approaches, the improvement of the building fabric, the changing of energy consumption systems among the people, and the application of renewable energy. The inclusion of renewable energy as one of the approaches needed to achieve energy efficiency discourages the promotion of reckless or poorly-regulated fossil fuel combustion which encourages the production and release of greenhouse gasses into the environment. Poorly-regulated fossil-energy-consuming appliances – such as tripod wood cookers, charcoal cookers, traditional wood fireplace, etc. – in many cases lead to energy wastage. Consequently, according to the report of Umeh (2023), the culture of purchase of used cars is already prevalent in the Nigerian market and is unlikely to change soon. Furthermore, these used car models are usually old and have high fuel consumption characteristics; this leads to high energy consumption, especially in a situation where there is poor metropolitan public transport system, which helps to reduce the cases of private car usage, save fuel, reduce CO_2 emissions, and save energy.

Behavioral patterns, which promote the use of energy-consuming appliances, should be checked such as the use of incandescent light bulbs. In the view of Khan and Abas (2011), incandescent bulbs are characterized with low THD (Total harmonic distortion) and high PF (Power factor) but they waste lot of energy due to poor 1–2% efficiency. This implies that incandescent light bulbs are energy-consuming. Furthermore, Khan and Abas (2011) argued that the power requirements of fluorescent tube, Compact fluorescent lamps (CFL), light emitting diodes (LED) and electrode less fluorescent lamps (EEFL) are 4.35–5 times lower than bulbs for the same luminous flux and a 100 Watt incandescent light bulb produces same luminous flux as 18 Watt fluorescent tube, 23 Watt CFL, 15 Watt LED or 21 Watt EEFL. This implies that fluorescent tube, CFL, LED and EEFL are better light options for energy efficiency. Energy consumption can be way reduced in the operation of the cathedrals through the adoption of energy-efficient bulbs, instead of the energy consuming incandescent bulbs.

6.0. Energy-Efficient Building Design Options for Nigerian Roman Catholic Cathedrals

From the point of view of economics and environment conservation, it is more advantageous to attribute energy-efficient characteristics to the design of buildings, in contrast with the prevalent energy-consuming practices obtained in the building construction industry (Al-Jabri et al., 2004). According to Bolorforoush (2014), the Catholic Church has preached about the importance of environmental issues and taken systematic approach targeted at CO_2 reduction for the entire building stock of her religious buildings. This implies that the Catholic Church recognizes the importance of energy efficiency as a sustainable option for her religious spaces. In line with this motive, through proper design considerations and construction techniques, energy efficiency can be achieved in Catholic religious buildings such as Roman Catholic Cathedrals In order to maintain optimum indoor microclimate for Roman Catholic Cathedrals. Proper care should be taken to ensure that the components and services of the building structure – which make direct contact with the exterior environment – are effectively designed such that optimum indoor air quality is achieved with the lowest possible cost.

6.1. Design options the walls

The walls should be designed such that the impact of solar radiation is reduced to the barest minimum on the indoor environment. Material of construction should be such that can bridge thermal conduction, evacuate heat through convection, and self-cool through evaporative cooling, in a sustainable way, without heating up the indoor air. With regards to bridging thermal conduction in hot climates, cavity walls are used to achieve this aim (Al-Jabri et al., 2004). Ventilating the cavity wall by providing adequate means of cross ventilation within the walls can help to evacuate hot air trapped within the air gaps of the walls in order to keep the indoor air temperature at optimum condition. This process entails the construction of the building walls, separated by an air gap, and braced with metal ties. Notwithstanding the lower thermal insulation characteristics of cavity walls, they are costly and more time and labor-consuming (Al-Jabri et al., 2004). Cavity walls or double skin wall is a good recommendation to reduce the energy consumption during hot weather in a tropical country like Nigeria. It is well known that concrete has more thermal conductivity than air (Al-Jabri et al., 2004). Therefore, introducing air gaps in the concrete block will reduce the thermal conductivity of the concrete block. For a better thermal resistance performance for a tropical country like Nigeria, providing sources of cross-ventilation in the wall will help to evacuate trapped hot air within the skins of the wall, thereby keeping the indoor environment cool.

Low-weight concrete technique can be used to reduce the density of concrete and increase its thermal resistance (Al-Jabri et al., 2004). This is achieved by causing air bubble to be trapped within the concrete in order to make it less dense and more thermal resistant. According to the Research carried out by Al-Jabri et al. (2004), air-entrained concrete walls or low-weight concrete walls possess the same thermal resistance principle of cavity walls. This is because, according to Al-Jabri et al. (2004), the thermal behavior of concrete is related to its density; the thermal resistance of a concrete wall increases as its density reduces. Air bubbles or air entrainment [within a concrete wall] – which are less dense than concrete – reduce the density of the concrete and make it more thermal resistant than a concrete without air bubbles or entrainment.

6.2. Design options for the windows

The windows should be designed such that the impact of solar radiation is reduced to the barest minimum on the indoor environment. The main purpose of a window is to allow daylight into a building, provide visibility, and to shield the users from possible harsh exterior climatic conditions. The various performance requirements of a window according to Bülow-Hübe (2001) are penetration of sunlight and daylight, visibility, thermal insulation, control of ventilation and air flow, control of water vapor flow, protection against precipitation, insulation of sound, strength and rigidity, durability, fire protection, burglary protection, protection from insects, easy to clean and maintain, safety, aesthetic appeal, economics, and sustainability. In order to achieve energy efficiency through windows, we must have to improve the thermal resistance properties of the windows. Windows need to be transparent, in order to improve visibility, but the disadvantage of this property is that when sun rays pass through the window pane into the indoor environment, they warm up the indoor space. To this effect, Bülow-Hübe (2001) opined that one needs to apply thermal-resistant technologies in window design and construction in order to reduce indoor heat gain, achieve optimum indoor air quality, reduce energy cost of cooling, save cost and energy, and improve energy efficiency.

Heat gain through windows can be reduced through the use of solar control pane, photochromic panes and window shading. Solar control pane is achieved by adding a metal oxide to the glass so as to create an uncoated body-tinted absorbing glass (Bülow-Hübe, 2001). In the view of Bülow-Hübe (2001), the solar control pane is usually placed on the outer pane, in a double-window combination, and the absorbed heat will be mostly reradiated and converted to the exterior. Photochromic panes are characterized with self-adjustable transmittance, with respect to sunlight intensity, and are very useful for several reasons. Photochromic panes should be transparent enough at low intensity, whereas at full solar intensity, their transmittance should be reduced to about the optimum values for conventional indoor daylighting requirements (Hoffman, 1990). The controlled flow of radiant energy can lead to important energy savings, by decreasing the cooling loads in buildings.

Solar screening technique is an energy-efficient application of blocking the windows from experiencing direct solar radiation, such that only diffused daylight can be transmitted by the window panes into the interior space (Bülow-Hübe, 2001). Facade screens, as means of solar screening, are solar protection membranes which are designed and engineered to shield the windows from direct sunlight. They can be installed directly over existing structures or incorporated into new buildings or retrofit work facades. Solar screening is also achieved using wall indentation techniques, which involves the recession of window positions towards the interior, in order to shade it from direct sunlight. This technique is an energy-efficient means of keeping the indoor air quality at an optimum level.

Translucent concrete, which is a new energy-saving building material which permits the transmission of light into the indoor environment due to the presence of embedded optical fibers in application, should be used where possible as an architectural wall and a structural component of the building (Tuaum et al., 2018). According to Tuaum et al. (2018), the translucent concrete could perform up to 22% of light transmission which is sufficient illuminance for residential and ecclesiastical buildings. This implies that translucent concrete can be successfully used as an energy-efficient construction material for sustainable construction and green building development (Tuaum et al., 2018).

6.3. Design options for the roof

The roof should be designed such that the impact of solar radiation is reduced to the barest minimum on the indoor environment. A cool roof consists of a passive thermal resistant solution technique and characteristics which helps to reduce the cooling load and energy demands on a building fabric (Parker et al., 1998). According to Parker et al. (1998), cool roof can be surfaces which reflect sunlight and emit heat more efficiently than other dark roofs. In the view of Uemoto et al. (2010), roof surface temperature can exceed the temperature of the other surrounding surfaces covered with vegetation by 20°C. Consequently, a cool roof reduces energy bills by reducing energy cost of powering mechanical air conditioning systems. Roof light application is another way to achieve energy efficiency.

Through roof lighting, the distribution of lighting can be even better on larger structures, and as much as three times more than the same area covered by vertical glazing (National Association of Roof lights Manufacturers, 2009). According to Wang et al. (2013), a case study in UK revealed that around 70% of lighting energy savings and 45% overall CO_2 emissions reduction can be achieved for an industrial building with 12% to 15% roof lights. However, heat gain can be optimized less than 40% in this case.

6.4. Natural ventilation design options

According to Yang and Clemens-Croome (2012), natural ventilation utilizes the natural forces of wind and buoyancy to introduce fresh air and distribute it effectively in buildings for the benefit of the occupants. This implies that fresh air is required to achieve a healthy, fresh, and comfortable indoor environment for people to work and live in. Natural ventilation can be achieved in the Roman Catholic Cathedrals through various ways.

The extent to which the stark or buoyancy-driven ventilation operates is governed partly by the wind pressure and partly by the design of the openings and the internal layout of the building (Yang and Clemens-Croome, 2012). According to Yang and Clemens-Croome (2012), stark or buoyancy-driven ventilation is enhanced by thermal differences and pressure differences of air. This implies that cold air enters through openings below, rises upwards when it gets warm, and exists through openings or vents provided above.

In addition, the wind tower ventilation works with the general principle that wind speeds are faster at greater heights (Yang and Clemens-Croome, 2012). As a result of the height, the wind tower enhances the positive wind pressure on the windward side and the wind is then directed through the tower into the building (Yang and Clemens-Croome, 2012). This implies that the wind tower is built to capture fast-moving wind at a higher altitude, such that the captured air is channelled down to the required spaces. During night hours the cool night air reduces the temperature of the structure alongside the interior air, and the heavier air then flows downward, cooling the interior spaces after the heat of the day (Yang and Clemens-Croome, 2012). The cooling effect of the wind tower can improved by installing materials with evaporative-cooling properties along the path of air travel to cool the air further (UNEP, 2019).

Furthermore, the courtyard effect is another method of natural ventilation which works with the ventilation principle of a courtyard. In hot southern China for example, the courtyard houses are built with multiple stories to encourage cross ventilation flow incorporating natural cooling effects (Yang and Clemens-Croome, 2012).

6.5. Evaporative cooling design option

Another means of achieving energy efficiency is through the use of evaporative cooling systems. Evaporative coolants work with the principle of achieving air cooling through the process of evaporation (UNEP, 2019). Monish Siripurapu, an Indian architect applied the science of evaporative cooling to achieve sustainable air cooling, using a continuously wetted beehive-like assembly of hollow earthen cylinders (UNEP, 2019). According to the experiment carried out by Monish, about 500 pieces of continuously wetted earthen baked cylinders [of dimensions; 30cm length, 7.5 cm diameter, and 1 cm thickness] all arranged to form a circular beehive-like structure with a total surface area [internal and external] of 60 m², is capable of cooling hot air at 42°C, as it passes through the continuously wetted earthen cylinders at a velocity of 4 m/s to a temperature of 36°C. This air-cooling method is sustainable, affordable and artistic.

6.6. Renewable energy options

Biomass and biofuel technologies are renewable energy tools, which are used for the conversion of organic biomass matter to gaseous or liquid fuels respectively in order to promote energy efficiency (Sesan, 2008). The use of biofuel technology to satisfy the energy demands of Roman Catholic Cathedrals should be encouraged to ensure energy efficiency. The sources of biofuel include organic components such as human waste, animal waste, agricultural waste, wood, charcoal, etc. (Sesan, 2008). These are important energy sources for energy efficiency. The biofuel deposit in septic tanks is a cheap source of biofuel and can be harnessed for cooking and heating purposes using adequate biomass technology.

The abundant solar radiation in Nigeria can be harnessed using effective solar photovoltaic technology to produce renewable electrical energy to power Roman Catholic Cathedrals. Sesan (2011) opined that encouraging indigenous companies to invest in solar photovoltaic technology in Nigeria could help to reduce acquisition cost of this technology owing to the fact that most of this technology are imported from foreign countries.

Solar thermal technology is used to generate heat energy from the sun. The energy can be used for solar drying, solar water-heating, solar cooking, etc. (Sesan, 2011). The energy can also be converted to electricity in collaboration with steam turbine technology to power Roman Catholic Cathedrals. In the view of Sesan (2011), despite the numerous energy-efficiency benefits of the solar thermal, the failure of Nigerian decision-makers at all levels to recognize it as a valid Energy supply option is a problem. This has, a long time, prevented solar thermal technology from reaching its full potential in Nigeria.
Wind energy is another energy-efficient means of powering Roman Catholic Cathedrals. Nigeria falls into the poor and moderate wind zones. Wind speed are highest in the coastal areas of the South and in the hilly regions of the North. In the opinion of Sesan (2011) this means that these regions will be the most economically viable site for wind energy development in Nigeria.

Small hydropower schemes are particularly advantageous because they can be developed independently of the National Grid; a feature which is especially desirable for remote electrification especially for Cathedrals and other facilities close to viable water bodies (Sesan, 2011). Sesan (2011) further argued that it is a bit surprising that small hydropower technology, which proves to be locally feasible, still suffers large-scale implementation in Nigeria.

7.0. Conclusion

Roman Catholic Cathedrals, being one of the oldest institutional buildings in history – while serving their purpose of spirituality and ecclesiastical administration – should provide optimum indoor air quality for the users using little energy in a sustainable manner as well as be aesthetically pleasing and iconic by standing out among other buildings within the same locality. Energy efficiency should be a design consideration and guide in the architectural design of Roman Catholic cathedrals.

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