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Energy efficiency design strategies in mixed-use buildings in Nigeria

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Abstract
There is an increased effort by governments and non-government agencies across the globe on the need to reduce energy consumption through energy-efficient buildings that make use of less energy. This study assessed energy efficiency strategies in general-purpose buildings in Lagos State, Nigeria. A qualitative research method and secondary data sources were adopted as the research design and source of data respectively. Likewise, content analysis was adopted to analyze the collected information. The findings revealed that energy efficiency strategies can be viewed holistically from the pre-building phase and building phase. During the pre-construction phase, energy-efficient design solutions include solar systems, energy-efficient building materials, building envelope, optimal site selection, and utilization of renewable energy resources (passive heating). On the other hand, energy efficiency design strategies for building phases are; conventional frame building systems, tunnel-form concrete masonry systems, precast construction systems, enhancing multiuse and using energy-efficient bulbs, and energy-efficient appliances. From the findings, the study concluded that when the identified strategies are applied in the focused building, there would be energy efficiency and improvement in human comfort.

Keywords: energy, design, efficiency, strategies, buildings, mixed-used, Nigeria

1. Introduction

The increasing use of energy and the depletion of fossil fuel resources are the outcomes of population growth and industrial changes. Unvaryingly, the situation has increased the energy used. For instance, over 40% of all energy used globally is utilized by the building industry (Cao, Dai & Liu, 2016) [5]. Therefore, the push for green building has led to the creation of new construction standards that speak to energy conservation and efficiency as well as carbon footprint. The aforementioned are significant issues that must be taken into consideration and followed. By 2030, it is expected that there will be eight billion people on the planet, which would result in a 40-50% increase in the use of food, water, and energy (Ochedi & Taki, 2019) [10]. In addition to contributing to air pollution, environmental harm, and global warming, the world's finite supply of fossil fuels may be exhausted as a result of growing energy consumption.

Mixed-use buildings have been on the increase over the years, particularly in the case study area, as a result of other developmental projects. An infrastructure type known as a mixed-use building combines different business, residential, and possibly hotel uses into one continuous structure (Rabianski, 2016) [15]. The building has components of a live-work-play ecosystem and is made for everyone. It is difficult to design a mixed-use building since one of the key components that ensure occupant comfort in a building is its HVAC system (heating, ventilation, and air conditioning), which needs enough energy to run well (Adebisi, Ayinla & Okeyinka, 2018) [1].

Despite the government efforts to enhance the energy efficiency, Nigerian building design and construction have not yet given the problem of energy efficiency much thought (Ghabra, 2017) [7]. Buildings have low thermal efficiency because rules and standards are not strictly followed, and new construction is frequently constructed without sufficient thermal insulation. As a result, residents must rely mostly on air conditioning to stay comfortable and other energy-inefficient equipment. Energy Sustainability is a crucial aspect of SDG's Agenda and therefore that of sustainable development in any megacity including Lagos. Moreover, architecture plays a significant role in promoting energy efficiency and sustainability (Adewumi *et al*, 2023) [2].

Aside from the practical issues identified on energy efficiency in Nigeria, the literature review established that studies on energy efficiency design strategies on users' comfort in selected mixed-used buildings are scanty. Therefore, further study is necessary to address energy inefficiency in the building typology. Due to the high rate of energy use in residential buildings, the need to ensure energy efficiency and the paucity of studies on the phenomena of the study, the current study seeks to assess the various energy efficiency design strategies in use in the pre-building phase and building phase in mixed-use building in Nigeria.

2. Literature Review

Mixed-Used building

Mixed-use buildings have attracted various explanations as well as definitions from different facets in the architectural parlance. For instance, Rabianski, (2016) [15] defined a mixed-use building as a form of infrastructure that combines several uses, such as residential, commercial, and possibly hotel, into one building. The structure incorporates aspects of a live-work-play setting and is made for everyone. A different viewpoint on mixed-use development was offered who defined it as a type of urban development that blends commercial, office, residential, cultural, and recreational uses in any combination inside a single building or group of structures. Complete pedestrian networks are made possible by these seamlessly connected functions and activities. Mixed-use developments might be purposeful or accidental, arranged or not. An intentional process leading to a mixing of uses is anticipated by the Urban Land Institute (ULI) in their definition of mixed-use development. Plans for mixed-use development are usually more comprehensive than those for single-purpose development, and they cover a wide range of topics, including "the types and scale of land uses, allowable densities, and general locations on the site where different forms of development are to occur. A practical strategy for creating a sustainable future in the shape of a mixed-use building, a building with a combination of commercial and residential uses must be developed in light of the current trend toward energy efficiency and the great growth potential that appears ahead.

Building Energy Consumption

Contemporary structures typically use a significant amount of energy, as several studies have shown. Buildings are immense energy users, and as such, they have a big impact on the environment and resources. Almost half of the energy used globally is reportedly absorbed by the building industry (Piotrowska & Borchert, 2017) [14]. To substantiate the aforementioned, Sahebzadeh *et al*. (2017) [17] said that 30–40% of the energy used globally is usually consumed by modern structures. This fraction may increase in the future due to the continuous increase in the world's population and growing urbanization. Moreso, the growing population consequent of urbanization has varying effects on domestic solid waste generation and if it is not well managed the residents' well-being is endangered (Onamade *et al*., 2022) [12].

Consequently, when it comes to energy analysis for efficient energy, the residential sector is an important area to take into account. Operational and embodied energy is crucial for doing building energy assessments. In contrast to embodied energy, which is concerned with the energy used during a building's construction, operational energy is the amount of energy required to maintain a structure's operational functions for its lifetime, such as lighting, appliances, heating, and cooling (Olanrewaju & Adegun, 2021) [11].

Additionally, it lends credence to the assertion stated that, of all industries, the building sector has the most environmental impact and that this impact will only increase going forward. Put another way, as it is believed that the building sector is the main source of greenhouse gas emissions, which in turn cause problems like global warming and climate change (Sahebzadeh *et al*., 2017) [17].

2.1. Energy Efficiency Strategies

A building is considered "energy efficient" if it uses less energy while still offering its residents a respectable level of environmental comfort. Lately, total energy consumption has increased faster than population growth due to the rise in individual energy demand. (Alagbe *et al*., 2019) [3]. According to research, incorporating passive energy design principles into buildings can result in significant increases in energy efficiency. This ought to be taken into account while designing a building, choosing building materials, starting construction, and running the building. Based on the previously said, the present study's focus is on energy-efficient design strategies used during the pre-construction and building phases, as discussed therein.

2.2.1. Energy efficiency design strategies in the pre-building phase

Appropriate site selection: A key design parameter is the position of the hemisphere, slope, and aspect. Building location affects the microclimate, which is crucial for learning about climatic factors including humidity, air temperature, sun radiation, and air circulation that impact energy expenses. Some of the most crucial design factors that influence the amount of sun radiation and the velocity of air circulation around the buildings are the building's location and the distance between neighbouring buildings. Because of this, it is important to choose a building location in the area that will both benefit from and protect against renewable energy sources like the sun and wind. Therefore, building placement on the property must take into account the local climate to offer sufficient protection from the sun and wind. Colder, denser air accumulates in hollows and valleys in colder places due to lower nightly temperatures. Consequently, it is best to locate structures on slopes as opposed to in valleys in cold climates. Like valleys, these sloping locations benefit from more direct sunlight since they are less impacted by cold winds (Figure 1).

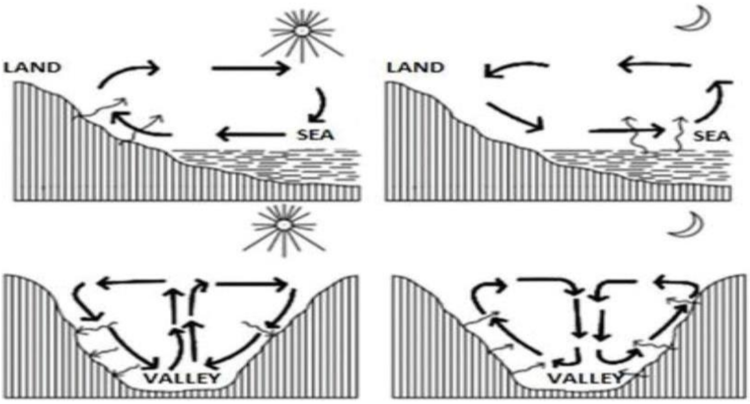

Fig 1: The change in climate conditions surrounding the building depends on the location of the building (Mohsen & Akash, 2001)

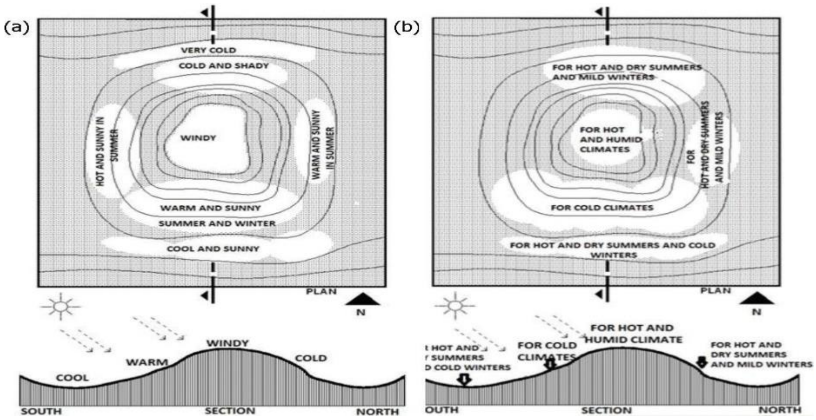

Fig 2: Appropriate land for habitation based on several climate zones (Lechner, 1991)

Two things to consider are (a) the microclimate surrounding a hill, and (b) the best locations for envelope-dominated buildings about the hill's climate. The type of construction and the surrounding conditions determine which side of a steep terrain is best for a project. The sites of envelope-dominated buildings, like residences and small office buildings, indicated in Figure 2 are recommended by the climate (mixed-use buildings). As a result, the latitude, the land's slope, and the amount of solar radiation entering the atmosphere are crucial factors.

Building Envelope

The elements of a building envelope are the walls, ceiling, floors, windows, and doors that divide the interior from the exterior of a conditioned space and allow thermal energy to enter or exit. It is an important reagent for both indoor and outdoor use when it comes to energy consumption (Mohsen & Akash, 2001) [19]. Although the cost of erecting an envelope accounts for 15–40% of the overall cost of construction, it contributes about 60% of life cycle expenses, particularly energy costs. Building skin regulates air, heat, cold, and light intake by acting as a filter between internal and outside environments. Winter heat gain and summer heat loss should be kept to a minimum via the building envelope.

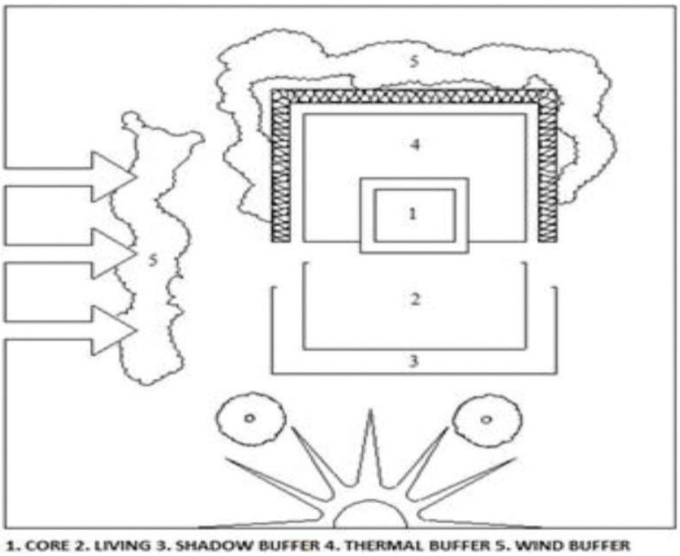

Fig 3: Spatial zoning

The outside walls, windows, flooring, and doors of the structure all have structural and physical properties that influence how much energy the building uses. The thermal efficiency, material thickness, and color of these components all have a significant impact on the building's capacity to regulate heat gain and loss.

Choosing Energy-Efficient Building Materials

Energy-efficient features should be included in building materials throughout both the manufacturing and consumption phases. The energy efficiency of buildings is significantly influenced by the materials used in construction. The manufacturing of building materials uses a significant amount of the total energy utilized during the building life cycle (especially embodied energy). Depending on the building techniques, climate, and other comparable factors, the percentage of energy used in the production of building materials to the overall energy used in a construction project with a 50-year life cycle can range from 6 to 20 per cent.

Use Renewable Energy Resources: Passive Heating

By using a mix of thermal mass, insulation, and solar access, passive heating absorbs, stores, and uses solar radiation to provide heat. Overheating is avoided by using shade and ventilation. Both passive and active strategies can be used to take advantage of renewable energy sources. The link between the solar system and the building determines the category of passive solar heating systems. Direct gain systems, indirect gain systems, and isolated gain systems are the three types of passive solar heating systems (United States Air Force, USAF, 2015). Windows, walls, floors, and other structural components gather and store heat, which is subsequently distributed throughout the interior, in a passive solar heating system. The thermal mass gradually warms up after absorbing the remaining heat, and as Figures 4 and 5 illustrate, later that night, the heat is discharged back into the interior.

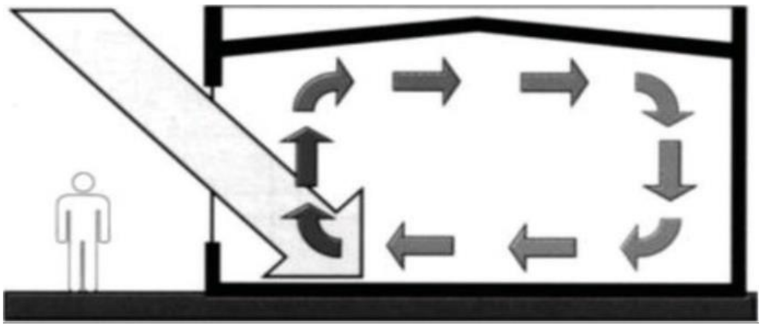

Fig 4: Direct gain schematic (Low-Energy Building Design Guidelines (2001)

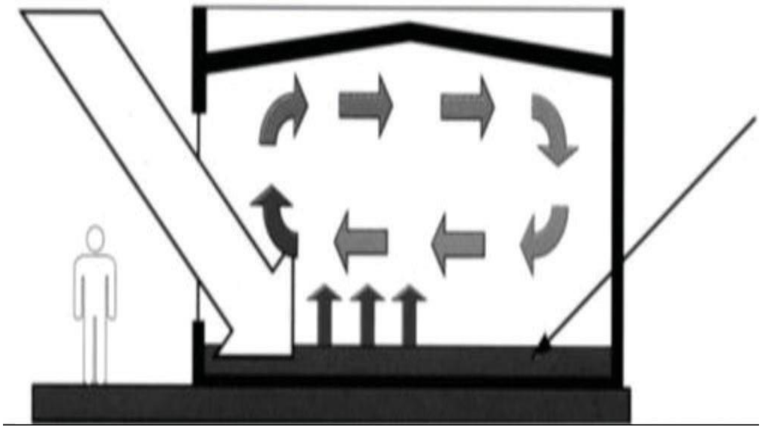

Fig 5: Direct gain plus storage schematic (Low-Energy Building Design Guidelines, 2001).

Passive cooling and Ventilation

Based on the setup of the application, categories are created for passive solar heating. However, it is more accurate to think of passive cooling as a group of scientific disciplines that concentrate on the fundamental heat sinks. Because so many practical systems require many heat sinks, this arrangement is beneficial to scientists and inventors but frustrating to designers and policymakers. Cool outside air is substituted for heated inside air through ventilation using a mixture of convection and evaporation to cool people by passing flowing air across their skin. The necessary air flow in passive applications is produced by the stack effect or wind. Fans may be used in hybrid applications to aid with movement, as seen in Figures 6 to 8.

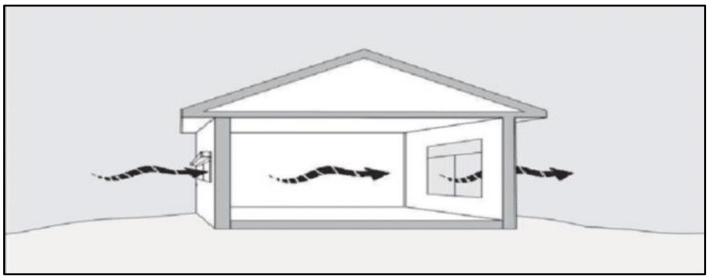

Fig 6: Use windows and doors for cross-ventilation

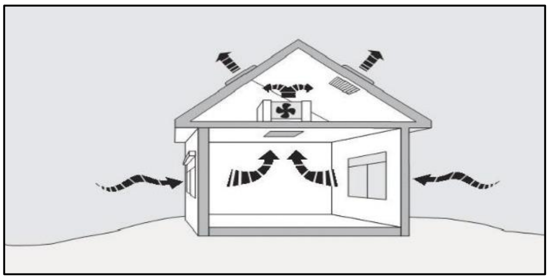

Fig 7: A whole-house fan

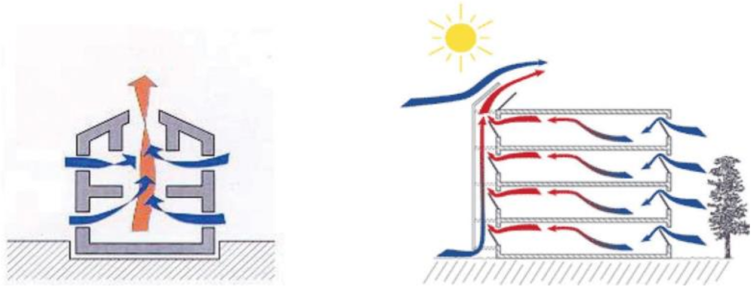

Fig 8: Movement in stack ventilation (Slessor, 2011)

Photovoltaic Systems

Photovoltaic (PV) systems are groups of parts that capture solar radiation, convert it into electrical energy, and make the energy useful. PV systems can be structured simply or complexly, and they are used to generate electricity in a wide range of applications, including electric power plants, cars, lighthouses, road lighting, and construction. Electric energy is created by a photovoltaic system, which then stores it for use under specific conditions before transferring it securely to the areas of use. Photovoltaic batteries, which are mounted on building roofs and fronts, transform solar energy into electrical energy, as seen in Figure 9.

Fig 9: Photovoltaic panels integrated into building

2.2.2. Energy Efficiency Design Strategies in the Building Phase

The construction and use of the building are included in the building phase. The building phase can be completed by employing energy-efficient equipment and choosing building procedures that need less energy. Building systems affect how much energy is utilized during construction. Study, for example, found that frame building uses less energy throughout its lifetime than reinforced concrete frame construction. Energy consumption varies in structures made of the same materials in proportion to variations in energy consumption in buildings made of different materials. Following three distinct building approaches, the energy consumption of the widely used reinforced concrete frame building includes:

Conventional frame building system: The primary characteristic of the conventional building method is the large amount of work force required to complete all manufacturing on the construction site. When the energy consumption of the equipment (concrete mixer, roof crane) used in the stages of concrete production and casting is considered, the conventional system's energy consumption is found to be low.

Tunnel-form Concrete Masonry System: A specific upfront investment is needed for the tunnel-form masonry system. The technique works well for continuous, large-scale productions. Energy consumption is considerable in lifting cranes since they are used to move large, heavy forms. The task of curing heaters and concrete plants increases the system's energy consumption.

Precast Construction Systems: Energy consumption in other systems is particularly high because most processes realized in the building area are manufactured in the manufacturing facility. Cranes that are raised are used in these systems to store, mount, and download components from vehicles to the worksite. Consequently, a significant quantity of energy is also used during these phases. Enroute to the construction site, heavy-duty trucks carrying readymade building components cause gridlock in addition to increasing energy usage.

In contrast, conventional systems have much lower energy consumption but have a greater negative impact on the formation of solid waste. Buildings made of the same material can be constructed using a variety of techniques, as demonstrated by the reinforced concrete building system. Concrete pumps, transport mixers, lifting cranes, and other heavy-duty vehicles use a lot of energy. Because of this, construction techniques that use less energy should be chosen, provided that building quality is not compromised. Building energy efficiency during the building period is achieved by the applications specified during the design process. In addition, there is a chance that the applications listed below will result in significant energy savings over their use.

Enhancing Multiuse: The integration of residential, commercial, and retail spaces is encouraged by sustainable development. People can reside close to their places of employment and shopping as a result. Because of this, the development of a community differs from that of conventional suburbs. The land is safer when it has the possibility for 24-hour activity.

Using energy-efficient bulbs and energy-efficient appliances: For instance, one of the most energy-efficient and quickly evolving lighting technologies available today is the light-emitting diode, or LED. A building's architecture informs the lighting requirements. The size and positioning of windows as well as the locations of buildings will determine how much illumination is needed, even during the day. By using automatic controls that are dependent on daylight availability, building window orientation, and room usage, the requirement for lighting is reduced.

High-performance air conditioning, heating, and ventilation systems: HVAC (heating, ventilation, and air conditioning) systems have a significant impact on how much energy buildings use. HVAC systems and building requirements are related in that highly efficient building envelopes lessen the requirement for HVAC systems. Buildings with well-thought-out designs can require fewer HVAC systems. Increases in HVAC system efficiency can result in significant cost savings. The entire savings will depend on the total amount of heating and cooling that the building requires, for example, if the energy efficiency of the air conditioner or heating boiler is increased. An adequately insulated building envelope lowers the energy requirements of the HVAC system. With careful building planning, the building can be divided into thermal zones of the appropriate size, lowering the demand for heating, cooling, and ventilation.

2.2.3. Previous Studies

Conducted a study on the optimization of a residential house's thermal behavior and energy efficiency via energy retrofitting in various climates. The researchers offer a comparative evaluation of over 20 different building retrofitting scenarios. Using the "feasible envelope characteristics," the research offers design codes that recommend a workable and optimum retrofitting plan while preserving thermal comfort and a baseline reference that is specially created for thermal energy efficiency.

In another study revealed that enveloped buildings such as structural buildings encompass thermal shield that connects the building and its conditioned interior spaces and thus allow for the transmission of thermal energy to the surrounding environment. It was also established that structural envelopes account for 15% - 40% of total construction costs.

Furthermore, Mirzaei *et al*. (2016) [8] used a case study to identify some benefits of mixed-use buildings. These benefits include reduced energy consumption when appropriate construction techniques are used, fewer vehicle trips, lower fuel consumption, and less reliance on cars, all of which contribute to the building's increased energy efficiency. Their research further showed that energy-efficient buildings are made to ensure that the least amount of energy is used in the building possible. This helps to lower the capital costs associated with buying mechanical equipment, ongoing maintenance costs, and energy consumption.

Likewise, in their study provide an overview of the energy efficiency of buildings in Tropical climates with an emphasis on Passive Techniques. The scholars critically review and analyze the different passive cooling techniques that could be adopted in the tropical climate and factors affecting their choice of selection; to contribute to the development of guidelines on how to mitigate the effect of climate change especially in Nigeria, as well as in the tropical regions.

In addition also looked into how energy-efficient design techniques affected the comfort of users in a few chosen mixed-use buildings in Lagos State, Nigeria. A quantitative methodology was used in the study. Data was collected using an organized questionnaire. The data was analyzed using SPSS (Statistical Packages for Social Sciences). Infographics (tables, and graphs) were used to display the outcome, and the results revealed that one of the most crucial strategies that affected every aspect of human comfort was building orientation. This finding implies that improving occupant comfort should be the primary goal of early design when implementing energy-efficient building practices.

Ochedi and Taki (2019) [10] carried out a study on energy-efficient building design in Nigeria using hourly weather data for 10 years. The performance of the building was examined, along with potential areas for improvement in terms of various orientations, glazing kinds, and shading mechanisms. Based on adjustments in building orientation, glass types, and shading device use, the simulation results demonstrated lower energy use. Based solely on natural ventilation, the results show a 29.45% reduction in solar gains and a 1.90% annual operative temperature. This indicates that by employing appropriate glazing, building orientation, and shading devices on the building envelope, it is possible to significantly cut energy usage and increase people's well-being. According to the study's findings, architectural designers and engineers should prioritize a variety of design possibilities over one or a small number of architectural elements to significantly reduce the overall energy consumption of residential structures.

3. Methodology

The thrust of the current study was to assess the various energy efficiency design strategies in use in the pre-building phase and building phase in mixed-use buildings in, Lagos Nigeria. To achieve the objectives, a qualitative research method was adopted and secondary data sources were adopted. The secondary sources used included; academic journals, textbooks and periodic papers on the constructs of the study. For the analysis, content analysis was adopted to analyze the collected information.

4. Results and Discussion

Using both qualitative research methods and content analysis, the findings revealed that there is an increased use of energy in residential buildings globally and Nigeria inclusive. To address the situation, the current study revealed that energy efficiency strategies can be viewed from two perspectives. First, energy efficiency design strategies are in use in the pre-building phase. The strategies include; appropriate site selection, building envelope, choosing energy-efficient building materials, use of renewable energy resources (passive heating), and photovoltaic systems. Second, energy efficiency design strategies used in mixed-use buildings in Nigeria include; conventional frame building systems, tunnel-form concrete mansory systems, precast construction systems, enhancing multiuse and using energy-efficient bulbs and energy-efficient appliances.

6. Conclusion

The study assessed the energy efficiency design strategies in mixed-use buildings in Nigeria. The results demonstrated that there are various energy-efficient strategies applicable in mixed-use buildings the conclusions thereby suggested that when applying energy efficiency measures available in both pre-building and building phases, there will be energy efficiency in the residential buildings and improvement in the human comfort. Based on the study approach and objective, the study contributes to the body of knowledge by providing empirical evidence on energy-efficiency strategies applicable in mixed-used buildings.

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