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Improving Thermal and Energy Performance of Residential Buildings in Nigeria by Developing and Using Eco-Friendly and Sustainable Local Materials

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ABSTRACT

The effort to consume more energy inside buildings is driven by the extraordinarily high temperatures and intense sunlight which is a problem in most developing countries, especially those in tropical climates like Nigeria. This study investigates how locally produced, environmentally friendly materials enhance the energy and thermal efficiency of residential structures in Nigeria. The study adopted a literature approach, and the outcome shows that sustainable local materials such as wood, bamboo, straw bales, earth, clay brick, stone, timber, and laterite have the advantage of accessibility, biodegradability, energy effectiveness, reusability, thermal comfort, and ozone friendliness, as such the use of these materials develops and optimise the thermal and energy performance of residences. As a result, residential structures may use resources more efficiently, have less impact on the environment, and perform better; economically, environmentally, and socially. The study recommended that that residential buildings need to continually adapt to technology breakthroughs, and regulatory and legal requirements to meet the dynamics of the built environment to develop and improve thermal and energy performance and sustainability in buildings.

Keyword: Sustainable local materials; Energy; Thermal Performance; Residential buildings

INTRODUCTION

Numerous individuals have moved from the rural to cities ever since the early 20th century's industrial revolution, which has aided in the growth of the economy (Lehmann, 2021). According to projections, 60% of the world's population will reside in metropolitan areas by 2030, necessitating the need to maximize the space within these buildings (Abubakar and Aina, 2019; Campisi, Severino, Al-Rashid and Pau, 2021). Individuals spend most of their time indoors, thus buildings need to be in good shape in terms of thermal and energy performance these (Alves, Gonçalves, and Duarte, 2021). According to Kalhor and Emaminejad (2020), 35% of the energy used worldwide in 2019 was used by the building industry. Buildings located in urban regions of developing countries use the majority of the energy, and because of the modernization of buildings in the construction industry, local materials, and climatic conditions are disregarded. Omer and Noguchi (2020) contend that using local resources in residential buildings is essential to establishing a secure and comfortable living environment. Heating, ventilation, and air conditioning (HVAC) systems require around 50% of the energy in a structure to provide thermal comfort. As a result, ensuring thermal comfort in buildings has always been one of the primary concerns of architects around the world, with residential buildings holding a special place in this regard (Homod, Almusaed, Almssad, Jaafar, Goodarzi and Sahari, 2021). Therefore, buildings should be designed to be highly energy efficient in a variety of climates while also offering a suitable level of thermal comfort. These could be accomplished by utilizing locally produced building materials (Homod, Jegede and Taki, 2022).

Davydova, Turchenko and Usachev (2020) explained that it is feasible to increase safety, comfort, and resource savings by using locally created building materials and producing ecologically friendly architecture. The term local building materials (LBMs) refers to products made from locally derived raw materials or materials found naturally in the area. According to Jegede and Taki (2022), the majority of buildings in Nigeria are still built with traditional methods and materials (wooden, bamboo). Other examples of regional building materials include clay, stone, wood, straw, sheep's wool, fibers, hemp, and cork. Several reasons, according to Alade, Oyebade, and Nzewi (2018), work against the usage of LBMs for building construction in Nigeria. Legal acceptability, societal acceptability, dubious durability, setting-specific technology, cost ambiguity, and government double standards are a few of these. Despite these difficulties, materials including coconut palm, bamboo, wood, clay, and bricks, as well as earth, have advantages such as durability, aesthetics, cost-effectiveness, fire resistance, energy efficiency, and thermal comfortability. Kayode and Olusegun (2013) clarified that locally produced materials are accessible and more cost-effective than those that are imported. It is significant to mention that employing LBMs in residential building construction has several benefits, including impermeability to provide rain protection, suitability to dry zones due to their high thermal capacity, and promotion of sustainability (Alade *et al.,* 2018). Affordability, accessibility, biodegradability, energy efficiency, reusability, thermal comfort, and ozone friendliness are further advantages of LBMs. These are based on achieving sustainability in building operations (Alade *et al.,* 2018)

In the modern world, it is crucial to employ sustainable local materials to increase the thermal and energy efficiency of residential structures (Mariano-Hernández, Hernández-Callejo, Zorita-Lamadrid, Duque-Pérez and Garca, 2021). The necessity to develop homes in a more efficient and sustainable manner has become more important as a result of the rising energy consumption and the requirement to minimize greenhouse gas emissions. In contrast to contemporary homes, where the use of air-conditioning modern systems was necessary to meet the occupant needs in terms of thermal comfort, Bencheikh and Bederina (2020) demonstrate that the use of local materials approved a 100% cooling energy efficiency during warm days (the thermal comfort has been achieved passively). Therefore, using sustainable building materials in residential buildings like wood, bamboo, straw bales, earth, clay brick, and tile helps to reduce resource use, minimize environmental impacts, pose no risk to human health, and help to achieve sustainable social, environmental, and corporate plans through which residential buildings experience an improvement in energy efficiency and thermal comfortability (Orhon and Altin, 2020; Ali, Shukri, Patel, and Ahad, 2020). The three pillars of sustainable development state that the following are the primary benefits of using locally sourced construction materials in residential structures: economic sustainability calls for the construction of buildings using contemporary building techniques and locally sourced materials with high energy performance, social sustainability focuses on the use of locally sourced materials that reduce accidents and adverse effects on residents during operation and the creation of a safer working environment, and

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environmental sustainability calls for the production of less waste and efficient and sustainable energy use throughout a building's lifespan. (Manandhar, Kim, and Kim, 2019). It is against this background that this study exposes that improving the thermal and energy performance of residential buildings requires the use of environmentally friendly and sustainable local materials.

LITERATURE REVIEW

Sustainability Aspects of Building Materials

Sustainable building materials are those that perform better overall when compared to predetermined standards. Locally produced and sourced materials, transportation costs and environmental impact, thermal efficiency, occupant needs and health considerations, financial viability, recycling of building materials and the demolished building, waste and pollution produced in the manufacturing process, energy required in the manufacturing process, use of renewable resources, toxic emissions generated by the product, and maintenance costs are some of the criteria that are frequently used (Omer and Omer, 2013). Kumar, Alam, Zou, Sanjayan, and Memon (2020) reveal that sustainable building materials are those that minimize resource use, minimize environmental impacts, pose no or minimal risks to human health, support sustainable site design strategies, and come from companies that have sustainable social, environmental, and corporate guidelines.

Praticò, Giunta, Mistretta, and Gulotta (2020) highlighted the need to use locally sourced, raw construction materials to reduce air pollution from manufacture and transportation. This also generates jobs for residents. The project's localization affects how much money remains in the neighborhood. The environmentally friendly, economically advantageous, and locally sourced building solutions. Recycling is a crucial component of green construction that lowers the use of non-renewable resources, particularly mining operations, energy consumption, and transportation expenses. This covers the use of waste goods and recycled building supplies. Reusing ecologically harmful products that emit methane into the atmosphere when discarded in landfills or that leak hazardous compounds into the soil and groundwater is especially significant. After each material has undergone a three-stage process comprising preliminary study, appraisal, and selection, it may be regarded as sustainable (Lim, Chong, Ling, and Tan, 2021). The study is often undertaken by first obtaining technical data, such as material safety data sheets, results of indoor air quality testing, product warranties, features of the source material, information on recycled content, environmental statements, and statistics on durability. Building materials must then go through evaluation, which entails verifying the technical data acquired in the previous stage. An established tool for assessing environmental consequences is life cycle assessment (LCA). The last phase, selection, frequently entails scoring the particular environmental factors using tables and matrices. The product with the finest environmental qualities will be shown by adding up the scores for each material. But it's also crucial for sustainable development to take into account social and economic aspects (Hussain and Kamal, 2015).

Calkins (2008) established that the dangers to the environment and human health from sustainable construction materials should be nonexistent or extremely low. These materials should also be reasonably priced, meet low embodied energy requirements, be energy-efficient, eliminate or reduce generated waste, have minimal toxicity, save water, and make acceptable use of natural resources. Samuel, Dharmasastha, Nagendra, and Maiya (2017) examined the possibility of producing building supplies locally to guarantee thermal comfort in

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buildings and reduce the cost of building supplies, enabling the average Nigerian to afford housing. Numerous authors have argued that indigenous construction materials should be developed in order to lower the high cost of housing. Mpakati Gama, Wamuziri, and Sloan (2012) advised embracing indigenous construction materials that have the potential to improve the development of mass housing. According to the same researchers' assessment of public and private developers in Nigeria, 11.25 percent of private developers utilise local materials, and 12.5% use imported materials. 65% of public developers make use of local materials in the housing delivery process, whereas 55% of private developers use imported materials. The research therefore advised local, economical, and long-lasting materials for walls, roofs, and floors instead of overly relying on imported ones for the supply of sustainable housing by both public and private developers.

TYPES OF LOCAL MATERIALS USE IN RESIDENTIAL BUILDINGS

Timber

In addition to being one of the oldest construction materials, lumber is also one of the most adaptable, claim Viholainen, Kylkilahti, Autio, and Toppinen (2020). Regarding interior comfort and health concerns, it is okay. Timber is utilised in entire or partial building and roof structure constructions, either using pole timber, sawn timber beams, or glue-laminated sections. Floors, walls, ceilings, and roofs built of pole timber, sawn timber boards, or significant panels of plywood, particle board, fibrous board, or wood-wool slabs might be either structurally significant or not. As additional insulating layers, wood-wool slabs are employed. It is also employed as door or window frames and facings. The following are a few advantages of timber: All climatic zones may use it for building. It offers adaptable living conditions that are cozy and healthful. According to research by Alade, Oyebade, and Nzewi (2018), wood is frequently used in Ado-Ekiti, Nigeria, both for flooring and roofing truss members, making it easy to replace ceramic tiles and steel trusses, either of which are imported alternatives.

Stone

Stone is one of the oldest, most enduring, and most plentiful natural resources, according to Akadiri, Chinyio, and Olomolaiye (2012). It is a cheap building material if it is situated close to the construction site. Other construction materials can be created by processing. Three geological categories may be used to classify the stone types most frequently used in construction: Rocks that have undergone metamorphism include slate, quartzite, and marble, as well as igneous rocks like granite and volcanic stones, as well as sedimentary rocks like sandstones and limestone. As stated by Akadiri, Chinyio, and Olomolaiye (2012), several advantages include its high thermal capacity, strength, and durability, easy accessibility in hilly places, low investment requirements for extraction, impermeability to provide rain protection, and suitability for arid zones. In the work of Alade et al. (2018), stones and rocks can be utilized in place of imported sandcrete blocks and fiberglass, which are used for the substructure (foundation), the structural frame, and the walls, respectively. This backed up Kayode and Olusegun's (2013) research on the use of pebbles and stones as an alternative to concrete and other building materials.

Earth

Tiza, Singh, Kumar, Shettar, and Singh (2021) report that the earth is a natural resource that is one of the oldest and most adaptable and is frequently utilized around the world as a building material, according to studies. It is inexpensive, robust in compression, and has great heat insulation capability. Buildings can be monolithic or built of several materials like bricks, renders, and infills, or they might be partially or made of soil. Earth can be utilised for renders, base courses, rammed earth, direct moulding, straw clay construction, and soil blocks for foundations, walls, floors, and roofs. Earth-building methods include direct sculpting, rammed, poured, and sun-dried earth as well as lumps of ill-formed clay, chopped, tamped, and pressed blocks, as well as machine-molded adobe and extruded earth.

Earth is a widely available, affordable, easily workable material that can be used for most building components. It also has fire resistance, high thermal capacity, low thermal conductivity, low porosity, low energy input during processing, endless reusability of unstabilized soil, and environmental suitability. Several problems with building with earth include the excessive water absorption of unstabilized soil, which causes cracks and deterioration from repeated wetting and drying; the material's low tensile strength, low resistance to impact and abrasion; and its lack of intuitive acceptability in most countries due to the lack of building and performance standards (Fabbri, Morel and Gallipoli, 2018).

Thatch/Straw

In the majority of communities across the world, thatch is a prevalent construction material. It is a by-product of plants that have been grown, whether they were cultivated or not (Udoudoh and Bassey, 2021). Because a larger percentage of it is grown as grains on farms, large amounts of it might be obtained locally. Thatch is a common wall or roofing material for traditional homes. Raffia or palm fronts are utilized to make the thatch that is frequently employed as roofing material around riverine villages' shorelines.

Bamboo

Bamboo is among the original raw materials used in building construction, along with mud and wood. It is constructed from raffia or palm trees, which are abundant in the world's rain belt region and grow swiftly. (Asif, 2009).It could be used to make walls, roofs, floors, doors, and windows, or it can be utilized as support components. Building a bamboo home involves basic carpentry and masonry tools and skills, and it may or may not be filled with a soft mud mix. Bamboo canes used in buildings should not be exposed to moisture since bamboo is not a good foundation material. Concrete foundations are recommended because they protect the walls from the damaging effects of dampness. The plinth course may be constructed alongside the foundations with formworks in place, and the infill walls can be erected in between the vertical bamboo columns. Additionally, as demonstrated by Yadav and Mathur (2021), bamboo is commonly employed as a native construction material in place of steel reinforcement and structural steel for flooring in residential structures.

Mud and clay

Although clay is not present everywhere, mud is abundantly found across Nigeria, especially in the southern section of the nation (Udoudoh and Bassey, 2021). The kind, size, and style of the construction, as well as the intended user and the quantity and quality of the mud or clay to be employed, all influence these decisions. Adobe is one of the most often utilized building materials, according to the cultural practices of the rural population. When there is more clay present, adobe construction is often used; when there is less clay present, sod construction is more common.

REVIEW OF STUDIES ON LOCAL BUILDING MATERIALS (LBMS) IN NIGERIA

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Alade, Oyebade and Nzewi (2018) shown the potential of LBM as a substitute for imported building materials at various building construction phases. They believe that laterite-containing rocks and stones may be utilised to construct an extraordinarily strong strip foundation that will withstand the test of time. Laterite, like bamboo-reinforced terracrete, may be used to produce concrete-quality slabs when reinforced with bamboo or coconut palm. Timber may be leveraged to make high-quality flooring when properly treated and immersed in liquid preservation. Comparably, bamboo floor and foist, which are created by polishing and processing bamboo, are suitable building flooring materials. When properly blended with clay screening, cow dung produced a strong and beautiful floor. Fermented leaves and bitumen can be used to improve the flooring's moisture resistance (Kayode and Olusegun, 2013). Furthermore, bricks combined with laterite provide an excellent building wall with higher conductivity than hollow concrete blocks. In addition, a desired construction wall with high compressive strength is generated by stone coupled with laterite mortar or lime stabilised mortar, but a desirable building wall is made by coconut palm, bamboo, and timber treated as stakes inside the soil (Marut, Alaezi, and Igwe, 2020).

Earth configure cement when it comes to mixing concrete because of its cohesive characteristics. To achieve the appropriate strength and avoid wall cracking, earthen walls can be reinforced with a variety of additions (vegetables, stems, reeds, and straws). In addition to strength, laterite fortified with bitumen for a wall can repel ants and rodents. Clay and bricks are two of the most commonly utilised materials for wall construction. According to Garay, Pfenniger, Castillo, and Fritz (2021), clay products are important fields that require urgent exploration given the benefits associated with their use. Durability, aesthetics, thermal comfort, cost-effectiveness, and fire resistance, for instance. Alade *et al.* (2018) noted that depending on the species, bamboo in particular possesses a significant tensile strength. Some bamboo species' ultimate tensile strength has been shown to range from an average of 1,400 kg/cm to 2,800 kg/cm, which is about equivalent to the yield point of steel. Such materials are still a great sustainable local material choice for roofing.

This approach involves gluing the masonry units to a wooden framework, which will be removed once the vaults or domes have dried, much like sun-dried earth block bricks have been used in the construction of vaults and domes (Kayode and Olusegun, 2013). According to Alade *et al.* (2018), clay and bricks stand out among other materials for building walls. Earth-stabilized cement is a suitable plastering medium for finishes and fittings. Timber is an excellent cladding material, whereas stones may be used as a stone face on walls. According to Aredah, Baraka, and ElKhafif (2019), adopting LBMs in the supply of homes has several advantages, including cost savings and enhanced foreign exchange. Affordability, accessibility, biodegradability, energy efficiency, reusability, and ozone friendliness are further advantages of LBMs.

Thermal and Energy Performance

Weerasuriyaa, Zhanga, Gan, and Tan (2019) claimed that a special comprehensive framework was created by combining energy simulation modeling and CFD simulation multi-zone airflow modeling to calculate ventilation rates under the processes of wind-driven and wind-buoyancy-driven ventilation. The findings indicated that switching from mechanical ventilation to wind-driven natural ventilation might result in a building using up to 25% less power. By enabling buoyancy-driven natural ventilation, the power usage may be cut by further up to

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45%. A 25-story high-rise residential structure in a dry area that relies mostly on natural ventilation was designed by Liu, Gao, Zhuang, Shi, Xu, Guan, and Di (2023). According to the author, solar gains are the main source of the tower's heating and may be minimised by using glazing ratios of no more than 10% to 20%. Additionally, in a Canadian high-rise residential complex, Berardi and Manca (2017) evaluated the effect of raising a building enclosure's thermal capacity on energy savings. Phase Change Material (PCM) in lightweight buildings can reduce cooling energy consumption by 5% to 21% by using a higher degree of heat capacity, according to the authors' simulation results.

Lau, Salleh, Lim, and Sulaiman (2016) show that the different kinds of external shading devices were analysed in terms of energy savings for heating and cooling using IES_VE software. This investigation revealed that, in terms of technical performance, the exterior shading device performed better than the interior shading device. Utilizing the overhang might reduce Seoul's summer cooling burden by around 18% to 20%. Another research, which used a Nordic high-rise residential structure, used simulation to look at how airtightness, air leakage distributions, and external climatic factors affected air pressure levels and energy usage. The findings showed that the stack effect is significantly influenced by the airtightness of the envelope and the interior airtightness of shafts. According to Kosonen, Juha, Ilari, and Koikkalaninen (2017), 20% more heating energy may be saved using an envelope that is 0.5 m3/h/m2 airtight. Mirrahimi, Mohamed, Haw, Ibrahim, Yusoff, and Aflaki (2016) conducted a research in Malaysia where they assessed the internal thermal state of a high-rise residential building for a month. The results show that a living room facing the predominant wind on a higher floor may achieve an average air velocity of 0.52 ms 1 and over 90% thermal tolerance. 90% of the rooms in an optimised design had air ages of less than 6 minutes, compared to 50% of the rooms in a conventional design having ages of more than 30 minutes, according to the findings of Sui, Tian, Liu, Chen, and Wang's (2021) CFD simulation of adjusting building orientation and ventilation strategies. According to Adeniji, Muhammad, and Isah (2021), only 45% of Nigerians have access to electricity, which is the main energy source used in residential structures during the project's useable time. However, as seen in Figure 1, the residential areas of Nigeria use the most energy, making about 45% of the population, which is the country's largest energy consumer. According to Figure 2, the residential sector in Nigeria consumes an amount of energy that is relatively high when compared to other countries. If the current trend continues, the residential sector will always be Nigeria's largest consumer of that energy, regardless of the nation's annual production of megawatts of power.

Oyedepo (2012) explained that it is safe to assume that the energy consumed and CO2 produced will have a long-lasting degrading effect on the atmosphere and the nation at large if the number of homes with access to electricity is increasing and the source of electricity is not diversified to more renewable sources. To ensure a pleasant living for the present and future generations, it is vital to develop sustainable strategies for enhancing energy performance.

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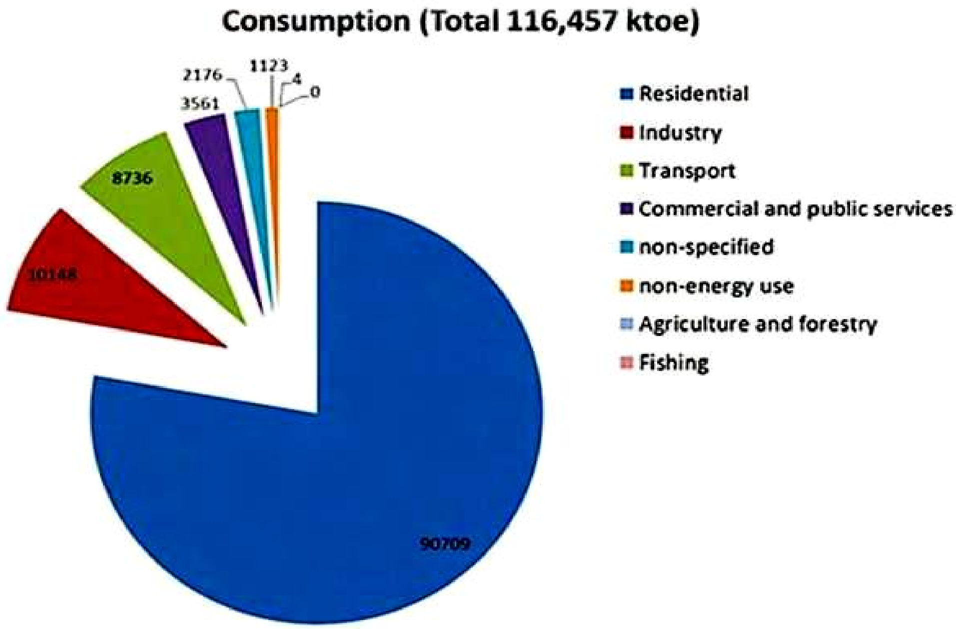

Figure 1: Energy consumption in Nigeria (Adeniji *et al.,* 2021)

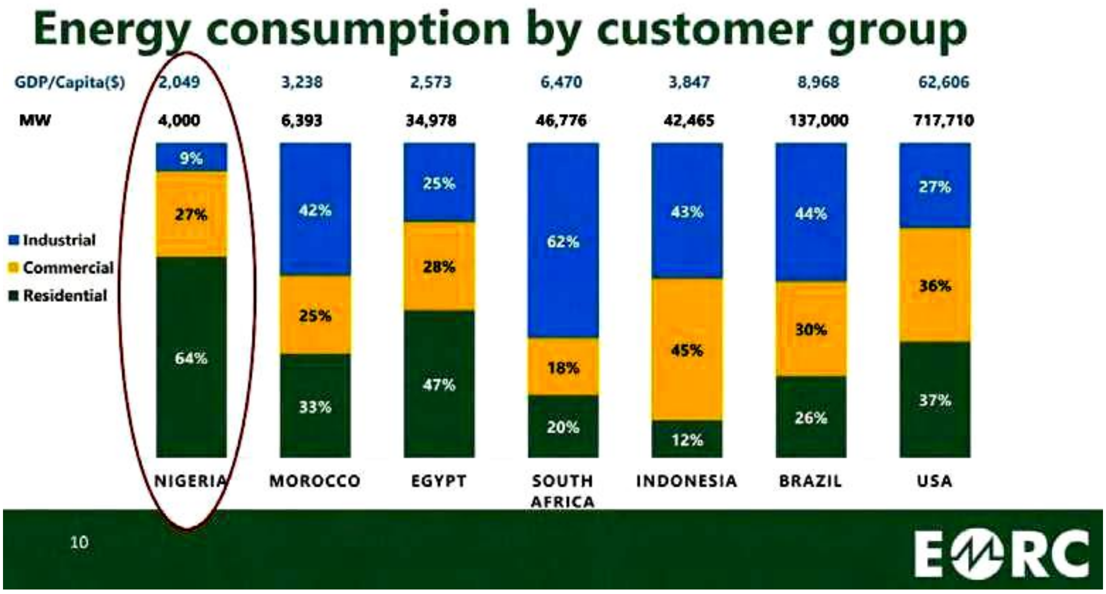

Figure 2: Energy consumption in Nigeria and other countries (Adeniji *et al.,* 2021)

Empirical studies

Hussain and Kamal (2015) study: an overview of energy-efficient sustainable construction materials. The study discovered that while natural resources are still being exploited, environmentally friendly construction materials must be produced to meet the demands of growing urbanisation. Sustainable structures are designed, constructed, maintained, repaired, and demolished with an emphasis on preserving global ecosystems while making efficient use of available natural resources. Selecting the appropriate building materials facilitates efficient use of energy. In the quickly evolving building industry, planners, architects, engineers, and builders are looking for new materials and technologies to use in future constructions that have advantages like longevity, enhanced indoor air quality, reduced life cycle costs, and resource and water conservation. A review of sustainable energy saving for residential structures by Adeniji *et al.* (2021). Data was gathered through desk research, which includes searching academic research databases for relevant articles using the keywords sustainable energy, residential construction, clean energy, and renewable energy. The study's conclusions demonstrated several approaches that have been developed as residential buildings' sustainable energy-saving measures. Nigeria has not yet looked into using the appropriate sustainable measures.

Sekisov (2021) explored the issues of attaining energy efficiency in the building of low-rise residential dwellings within the context of the employment of resource-saving technology. The study shows that, as a result of rising energy demand, simultaneous complexity and cost increases in the energy production process, and the worsening of environmental issues worldwide, energy efficiency and conservation have emerged as the most important areas for development in many countries. The dual thermal performance and energy efficiency of residential buildings in the hot and dry climate of Laghouat, Algeria, were analysed by Bencheikh and Bederina (2020). According to the results, the vernacular home was comfortable on warm days and had a 100% cooling energy efficiency, in contrast to a modern home where the use of air conditioning systems was required to meet occupant needs for thermal comfort (the thermal comfort was achieved passively). An estimated 39% decrease in energy consumption was included in the estimation of the energy performance differences between the two homes. Alwetaishi (2022) examined the possibilities of building design and environmental factors in his study of energy performance in residential structures. According to the study, the primary variable is the glass system's size, which may be altered to accommodate local heating and lighting needs. The findings also imply that energy consumption and thermal comfort in hot regions may be strongly impacted by thermal insulation and the ratio of windows to walls. Energy consumption has improved by 15% as a result of the WWR decrease to 20%. For both daylight quality and energy efficiency, WWR shouldn't exceed 30%. The cooling effect of reducing the window-to-wall ratio (WWR) is far greater than the heating effect. Fati, Latif, Souleymane, Thierry, Lewamy, and Joseph (2020) studied local materials' effects on the enhancement of indoor thermal comfort. The outcome demonstrates that when local materials are used in place of contemporary ones, the mean average building temperature is reduced. Finally, we conclude that one way to lower the rate of heat transmission into a room and energy use is to construct a structure with local materials. The problems, obstacles, and steps toward sustainability in thermal comfort and energy efficiency were addressed by Niza, Luz, Bueno, and Broday (2022). Energy levels, environment, set point kinds, building types, sizes, orientations, and economic considerations all affect real thermal conditions. Many considerations need to be made to create a thermally pleasant atmosphere.

Taher Tolou Del, Bayat, and Zojaji (2022) investigated how building plan shape affected thermal comfort in the hot and dry environment of Qom's traditional residential patterns. Field observations and a review of the literature have been used to collect data. Based on their construction plan form, the dwellings in this research were categorized. Climate Consultant software was used for climate analysis, and Ecotect and EnergyPlus software was employed for modeling. The results indicate that to provide thermal comfort in Iran's hot and

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dry climate, two essential components of the climatic design are the introverted plan forms and the building coverage ratio (BCR). Among the models that were analysed, the one-sided shape with a northeast-southwest orientation and a northeast location had the best plan form and the most hours (2609 h annually) in the thermal comfort range.

CONCLUSION AND RECOMMENDATIONS

In an attempt to make residential structures more energy-efficient and thermally pleasant, the paper outlines a passive means of achieving these goals. The approaches make use of locally available sustainable resources. In Nigeria, native sustainable elements such as wood, bamboo, straw bales, soil, clay brick, stone, timber, and laterite are utilised in residential constructions. These materials help to reduce resource use, minimize environmental impact, and achieve sustainable social, environmental, and corporate strategies through which residential buildings experience improvements in energy efficiency and thermal comfortability. Additionally, laterite is used to create bamboo-reinforced terracrete, which is useful for enhancing thermal comfort in buildings, when it is strengthened with bamboo or coconut palm. The review of the study also reveals that using local materials in home construction might help to actively reduce heat transmission into the room. The study concluded that just 45% of Nigeria's population has access to electricity, the primary energy source for residential structures during their usable era. No matter how much energy is produced by the nation, Nigeria's residential sector will always be the biggest user of that energy. This energy consumption is relatively high compared to that of certain other countries. Lastly, it was recommended that to generate and enhance thermal and energy performance as well as sustainability in buildings, residential structures should constantly adjust to technological advancements, legal and regulatory needs, and the dynamics of the built environment. Furthermore, further research is needed to determine the best ways to maintain and improve locally available building materials for the construction of environmentally friendly homes while taking into account location, technology, and our environment.

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