UNIABUJA Journal of Engineering and Technology

https://ujet.uniabuja.edu.ng/

ISSN: 2714-3236 (Online); 2714-3228 (Print)

Volume 2, Issue 1, 2025; 35-42

Empirical Review of Energy Efficiency in Mixed-Use Development in Victoria Island, Lagos State

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Abstract

Energy efficiency has become a central priority in public policy agendas, particularly in developed nations, due to its critical role in enhancing energy security, industrial competitiveness, and environmental sustainability. This study investigates energy efficiency in mixed-use high-rise developments, with a focus on Victoria Island, Lagos State. Mixed-use buildings integrate diverse functions within a single vertical structure, providing a solution to urbanisation challenges while fostering sustainability. This research reviews the energy architecture, electricity consumption patterns, heating, ventilation, and air conditioning (HVAC) systems, and the integration of renewable energy sources in these developments. Employing a qualitative approach, the study thematically examines relevant literature to identify factors influencing energy efficiency in mixed-use buildings. The findings underscore the need for sustainable practices and advanced energy-efficient strategies to optimize performance. Recommendations for improving energy efficiency in such developments are provided to support urban resilience and green building initiatives.

Keywords: *Energy conservation, energy efficiency, green building, mixed-use development, Victoria Island.*

1.0 Introduction

An empirical review of energy efficiency in mixed-use developments in Victoria Island, Lagos State, reveals significant insights into design strategies and their impact on user comfort and sustainability (Ochedi & Taki, 2022). Research indicates that energy-efficient design strategies, such as optimal building orientation and bioclimatic architectural approaches, are crucial for enhancing user comfort while reducing greenhouse gas emissions associated with high energy consumption in mixed-use buildings (Ochedi & Taki, 2022; Sholanke *et al.*, 2022). Furthermore, the integration of renewable energy sources, such as solar PV panels, can lead to substantial energy savings and improved operational efficiency, addressing the challenges posed by limited electricity access in Nigeria (Lawal et al., 2024). The development of critical sustainability indicators tailored to mixed-use buildings is essential for guiding future projects, ensuring they meet the needs of inhabitants while promoting urban resilience (Salami et al., 2021). Collectively, these findings underscore the importance of prioritizing energy efficiency in urban planning to foster sustainable development in Lagos (Murray, 2020). Internationally, the construction sector stands as a major consumer of environmental resources and a significant contributor to environmental pollution. Specifically, the building industry accounts for around 45% of society's material consumption (Vyas & Jha, 2019). Structures exert influence on the environment, either through the consumption of natural resources or by contributing to environmental degradation (Ibrahim *et al.*, 2022; Shittu *et al.*, 2021). Currently, developed nations, hosting only 22% of the global population, are responsible for 70% of the world's energy consumption (Bamisile *et al.*, 2021; Glavič, 2021). Energy efficiency in mixed-use developments is significantly enhanced through various design and operational strategies. Research indicates that optimizing energy balance using metrics like the Solar Cover Factor (SCF) can lead to substantial improvements in energy performance, potentially doubling energy balance in diverse designs (Natanian, 2023). Additionally, the implementation of efficient heating and cooling systems, such as district systems, can further reduce energy consumption and operational costs (Wang & Chen, 2023). The integration of Passivhaus design strategies promotes low-carbon living and resource efficiency, addressing the urban challenge of high energy consumption (Murray, 2020). Furthermore, the surrounding built environment plays a crucial role, as higher non-residential use can increase electricity consumption while reducing gas use (Woo & Cho, 2018). Finally, high-density mixed-use developments can significantly lower both operational and transportation emissions, showcasing a holistic approach to urban sustainability (Bowley & Evins, 2020). Collectively, these strategies underscore the potential for mixed-use developments to achieve remarkable energy efficiency. In comparison to global figures, energy consumption by buildings constituted 30–50% of the energy demand in Canada, the UK, and the USA (Himeur *et al.*, 2020; Kalua, 2020). 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).

The increasing use of energy has sparked worries about its effects on the environment, availability issues, and resource depletion. The most significant greenhouse gas (GHG) that is released into the atmosphere as a result of energy use is carbon dioxide (CO_2) (Yoro & Daramola, 2020). This is especially true when burning fossil fuels and biomass sources of energy are used to produce electricity. According to reports, there was a roughly 40% increase in worldwide CO_2 emissions related to energy between 2000 and 2016 (Variny *et al.*, 2021). Buildings accounted for approximately 40% of the global energy-related CO_2 emissions in 2015; residential buildings accounted for half of these emissions (Variny *et al.*, 2021). Global building energy consumption stayed constant year over year, according to the 2020 Global Status Report for Buildings and Construction, but energy-related CO_2 emissions rose to 9.95 $GtCO_2$ in 2019 (Bixio & D'Angiulli, 2021). This study aims to assess the current state of energy efficiency in mixed-use developments on Victoria Island, Lagos State, to achieve this aim, the objectives are to evaluate current energy consumption patterns; assess the impact of design features; and identify barriers and opportunities for improvement.

There is a great increase in the energy consumption rate in mixed high-rise buildings and it is alarming as it contributes greatly to the greenhouse gas effect. Around the world, building design has become a powerful tool that the construction sector may use to improve the environment rather than take advantage of it (Anzagira *et al.*, 2019). The Green Building Concept (GBC) is becoming a hot topic and gaining international attention as a possible remedy for various negative environmental and climatic repercussions of construction activities. Only the construction sector uses half of all resources, 45% of all energy, and contributes 35% of CO_2 emissions worldwide (Nematchoua *et al.*, 2021). Energy demand is relatively inelastic since energy is a necessity for most industrial sectors and households (John, 2022; Okorie, 2021). Green Building, often known as green design, and green architecture, is a building method that reduces the negative and disruptive impact of construction projects on human and environmental health (Yang *et al.*, 2022). The "green" architect or designer uses environmentally friendly building materials and construction techniques, or the environmental aspects, to protect the air, water, and environment (Bungau *et al.*, 2022). Meena *et al.* (2022) quoted Raouf & Al-Ghamdi, as "green building as a building that is energy and resource efficient and has minimal disruptions to the environment". Onubi *et al.* (2020) describe green building as that which addresses primarily the design and construction practices that impact the environment.

Nowadays, the majority of wealthy nations have made energy efficiency a top priority on their agenda for public policies. Energy efficiency is becoming a more important policy goal due to its benefits for energy security, industry and economic competitiveness, and the environment (e.g., lowering CO_2 emissions). There is no single, clear-cut quantitative indicator of "energy efficiency," and the phrase "energy efficiency" is nonspecific. Rather, to measure variations in energy efficiency, one needs to depend on a range of indicators (Napolitano *et al.*, 2023). Methods of increasing the energy efficiency of a home (e.g., by reducing heat loss) have an effect within and as part of an existing structure, the systemic qualities of which matter for the impact (or otherwise) of each additional measure (Asaju, Onamade, Chukwuka, Odefadehan, 2024; Dimitroulopoulou et al., 2023; Asaju, Adewumi,& Onamade, 2024). Urban sustainability and inclusion may not have a single top-down solution, but many bottom-up options can be used in their place (Adeboyejo *et al.*, 2022).

Reducing the impact of energy on the environment and human health appears to be highly appealing when done through efficient use of energy. Theoretically, achieving the same services with less energy use should relieve the strain on the infrastructure, lower costs, reduce occupational risks, reduce emissions of greenhouse gases and local pollutants, and limit dangerous exposures. Additionally, efficiency enhancement appears to have a lot of promise because, at the moment, only 20–30% of the chemical energy of the fuel burned is usually converted to heat or meaningful labour (Bai & Liu, 2021). Greater energy efficiency, or a higher ratio of useful energy output to input energy, essentially means more efficient technology, while behavioural considerations play a role in such utilisation. Mixed-use high-rise buildings have emerged as a transformative urban development model, integrating diverse functions within a single vertical structure (Al Khalifa, 2021). This approach represents an innovative response to the challenges of urbanisation, aiming to optimise land use, enhance urban liveability, and foster sustainability. The synthesis of residential, commercial, and cultural elements within the vertical confines of high-rise buildings contributes to the creation of dynamic, multifunctional urban environments. Mixed-use high-rise buildings are becoming increasingly popular in urban areas as they allow for efficient use of limited space while promoting walkability and reducing transportation needs (Samant, 2019). They also contribute to the creation of vibrant and liveable communities by providing access to a range of services and activities in a single location.

Designing and constructing mixed-use high-rise buildings requires careful consideration of the building's structural system, fire protection, ventilation, and energy efficiency.

In comparison to single-use buildings, mixed-use high-rise buildings have distinct energy consumption patterns due to the combination of residential, commercial, and office sectors (Naserisafavi *et al.*, 2022). These buildings consume energy for heating, cooling, ventilation, lighting, and other electrical appliances. Mixed high-rise buildings have a far higher energy consumption than low-rise buildings because of their vast surface area, high occupancy rates, and intricate designs (Mirshojaeian et al., 2021). The location, building design, occupant behaviour, and the kinds of activities performed in the building are some of the variables that affect the energy consumption of mixed high-rise buildings (Kim & Suh, 2021). The complexity of mixed-use high-rises requires comprehensive fire protection strategies to safeguard occupants and assets (Tracy *et al.*, 2023). Moreover, the growing population consequent of urbanisation 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).

Energy efficiency is a central consideration in the design and construction of mixed-use high-rise buildings. The vertical nature of these structures demands a careful selection of energy-efficient technologies and construction materials (Gupta & Chakraborty, 2021). Incorporating advanced insulation methods, energy-efficient lighting systems, and smart building management systems helps minimise the overall energy consumption of the building (Kumar *et al.*, 2022). Additionally, the use of renewable energy sources, such as solar panels or wind turbines, contributes to a more sustainable and resilient energy infrastructure. The implementation of green design concepts not only aligns with environmental goals but also serves to reduce long-term operational costs for both developers and occupants (Nayal *et al.*, 2022). Due to high energy usage, buildings and energy systems are dealing with a variety of problems. The population is growing, buildings are being used for longer, and people want more comfort and satisfaction in structures, that is causing the energy consumption in buildings to increase. Lately, total energy consumption has increased faster than population growth due to the rise in individual energy demand. (Alagbe *et al.*, 2019). According to research, incorporating passive energy design principles into buildings can result in significant increases in energy efficiency. Office buildings can use up to 40% less energy when passive energy design techniques including building orientation, natural ventilation, daylighting, and shading are used. It significantly reduces greenhouse gas emissions and improves indoor environmental quality (Ahmed *et al.*, 2021). Building energy efficiency and environmental effects can both be significantly increased by using passive energy design techniques. Promoting the use of passive energy design principles during the planning and construction of buildings is essential.

Building orientation is one of the most important passive design strategies used to enhance energy efficiency and reduce energy consumption in buildings. It involves the alignment of the building's layout concerning the sun's movement, prevailing wind direction, and site topography. The orientation of the building determines the amount of solar radiation that the building will receive and the amount of shading required to reduce solar gain (Obrecht *et al.*, 2019). In regions with hot climates, buildings should be oriented with their longest axis facing east-west, to minimise solar gain on the building's exterior surfaces. In contrast, in colder climates, buildings should be oriented with their longest axis facing north-south to maximise solar gain and take advantage of passive solar heating. Building orientation is an essential passive design strategy that has a significant impact on the energy efficiency of buildings. It is a practical method for lowering energy use, enhancing indoor comfort, and improving a building's overall environmental performance.

Current research indicates that conventional HVAC systems account for over 50% of a building's overall energy usage. Nonetheless, the energy efficiency of HVAC systems can be significantly increased by enhancing the control system or utilising particular energy-efficient techniques, such as thermal energy storage (TES), exhaust heat recovery, and evaporative technologies (Xu et al., 2019). Taheri et al., (2022) provide a review of the main mechanisms adopted in the last decades to improve the performance of HVAC systems. TES systems are addressed as an effective solution for space and water heating, space cooling and air conditioning (Dincer & Rosen, 2021). Incorporating passive design strategies such as proper orientation, shading, and natural ventilation; utilizing high-performance insulation, windows, and doors to enhance thermal efficiency; implementing energy-efficient HVAC (Heating, Ventilation, and Air Conditioning) systems and incorporating renewable energy sources like solar panels; water conservation, sustainable materials, waste reduction and recycling further contribute to energy-efficient design (Saleh *et al.*, 2024).

These strategies involve utilising architectural and environmental features, such as proper building orientation, shading elements, and natural ventilation, to optimise energy consumption within a structure (Pan *et al.*, 2024; Zoure & Genovese, 2023). Kumar *et al.* (2020) said utilising high-performance insulation involves selecting and installing materials that effectively resist heat transfer, minimising the exchange of heat between the interior and exterior environments. By incorporating these high-quality components, a structure can better retain or repel heat, resulting in improved energy conservation and a more comfortable indoor environment (Ma *et al.*, 2021). This approach promotes energy efficiency and sustainability in the built environment.

Sustainable building materials further play a pivotal role in achieving energy efficiency within the construction industry, offering a pathway towards environmentally responsible and resource-efficient building practices (Hafez *et al.*, 2023). The integration of sustainable building materials encompasses a range of eco-friendly options, each contributing to the overarching goal of creating energy-efficient structures that minimise environmental impact (Abera, 2024). Materials like recycled steel, reclaimed wood, and bamboo require considerably less energy to manufacture compared to their conventional counterparts (Zahoor *et al.*, 2024). By reducing the embodied energy in construction materials, the overall environmental footprint of a building is diminished (Zahoor *et al.*, 2024). Additionally, sustainable materials often possess superior thermal properties, providing enhanced insulation and reducing the need for excessive energy consumption in heating or cooling systems (Basyouni & Mahmoud, 2024). This inherent thermal efficiency not only contributes to lower energy bills but also aligns with the principles of sustainable design by promoting occupant comfort (Asaju *et al.*, 2024).

The life cycle of sustainable building materials underscores their contribution to energy efficiency. These materials are often selected for their durability, longevity, and ease of maintenance, reducing the need for frequent replacements or repairs. This durability not only minimises the energy-intensive processes associated with manufacturing new materials but also extends the operational life of the building. As a result, structures constructed with sustainable materials exhibit a prolonged period of energy-efficient performance, fostering a more resilient and environmentally conscious approach to construction (Alugbue *et al.*, 2024).

1.1 Theoretical Framework

Energy efficiency in mixed-use developments in Victoria Island, Lagos State, is a critical aspect of urban sustainability, given the high energy consumption associated with urban living. The integration of energy-efficient design strategies can significantly reduce greenhouse gas emissions while enhancing user comfort. This review synthesises key findings from various studies to highlight effective approaches to achieving energy efficiency in such developments.

1.2 Energy Consumption and Design Strategies

Urban areas account for 75% of global energy consumption, with mixed-use developments offering a unique opportunity to optimize energy use (Murray, 2020). Effective design strategies, such as building orientation and the use of passive design principles, can enhance energy efficiency and user comfort (Sholanke *et al.*, 2022). The implementation of multi-energy systems (MES) can further optimize energy consumption by integrating various energy sources and improving operational efficiency (Klemm & Vennemann, 2021).

1.3 User Comfort and Sustainability

User comfort is paramount; energy-efficient designs must prioritize human comfort to ensure habitability (Oru *et al.*, 2024; Sholanke *et al.*, 2022).

The development of critical sustainability indicators tailored to mixed-use buildings can guide architects and planners in creating resilient urban environments (Salami *et al.*, 2021).

1.4 Challenges and Future Directions

Despite the potential benefits, challenges remain in the widespread adoption of energy-efficient practices. The complexity of modelling energy systems in mixed-use districts and the need for comprehensive planning frameworks are significant hurdles that require further research and collaboration among stakeholders (Klemm & Vennemann, 2021).

1.5 Empirical Review

Energy efficiency in mixed-use developments in Victoria Island, Lagos State, is a critical area of research, particularly given the increasing urbanization and energy demands. The empirical reviews highlight various strategies and indicators that can enhance energy efficiency while ensuring user comfort and sustainability.

1.6 Energy-Efficient Design Strategies

Proper building orientation significantly impacts energy consumption and user comfort, indicating that this aspect should be prioritized in the early design stages (Sholanke *et al.*, 2022), while the integration of renewable energy sources and efficient HVAC systems is essential, as studies show that although some energy efficiency strategies remain underutilized, there is growing adoption of daylighting and sustainable lighting systems (Ezema & Maha, 2022); moreover, surveys reveal that sustainability indicators must reflect the needs of inhabitants, highlighting the importance of community input in the design process (Salami *et al.*, 2021), and

Received: 20-11-2024 / Accepted: 10-12-2024 /Published: 31-03-2025

the development of Model City Plans by the Lagos State government underscores a commitment to holistic planning by incorporating mixed-use buildings within a broader sustainability framework, thereby promoting urban resilience (Hassan et al., 2024; Salami *et al.*, 2021).

1.7 Challenges and Opportunities

Despite the potential benefits, the adoption of energy-efficient practices remains low in some areas, particularly in high-rise buildings. This indicates a need for increased awareness and implementation of best practices across the building lifecycle (Ezema & Maha, 2022). Conversely, the push for mixed-use developments presents an opportunity to optimize energy use and enhance urban living conditions (Murray, 2020).

1.8 Gaps

Despite the recognized benefits of passive energy design methods, such as natural ventilation, daylighting, and shading, these strategies remain underutilized in high-rise mixed-use buildings, particularly in warm-climate regions (Ayorinde et al., 2024). Adapting these passive strategies for the specific climate and high urban density of Lagos could significantly enhance energy efficiency and reduce the reliance on mechanical systems for heating and cooling.

Although the document highlights the advantages of renewable energy, there is limited adoption of technologies like solar photovoltaic (PV) systems and wind turbines in mixed-use developments in Victoria Island. Understanding the barriers to renewable energy integration, such as financial limitations, regulatory challenges, and infrastructural constraints, could provide valuable insights for promoting the use of these sustainable technologies in high-rise buildings.

Lastly, while the importance of sustainability indicators is acknowledged, there is a lack of a comprehensive framework specifically tailored to mixed-use high-rise buildings in Lagos. Future research could focus on developing sustainability metrics that address the unique environmental, social, and economic conditions of this urban area, helping guide more sustainable development practices in the region.

2.0 Methodology

This study adopted a qualitative research methodology, focusing on a comprehensive review of existing literature to analyse energy efficiency strategies specific to mixed-use developments. The approach involved the following steps: selection of relevant academic articles, journals, and reports were identified using specific keywords such as “energy efficiency,” “green building,” “energy conservation,” and “mixed-use development.” The literatures were filtered based on relevance to mixed-use developments and recency of publication to ensure the incorporation of up-to-date findings. Articles were critically reviewed to extract data related to energy consumption patterns, green building practices, and sustainable design strategies. Thematic organisation of keywords includes building orientation, renewable energy integration, HVAC systems, sustainable materials, and community engagement in sustainability practices. These themes provided a framework for organising insights and aligning them with the study objectives. The data were analysed. Therefore, the insights from the analysis were synthesised to draw conclusions and propose actionable recommendations. These focused on enhancing energy efficiency in high-density urban settings like Victoria Island, highlighting strategies for integrating renewable energy and sustainable practices.

3.0 Results and Discussion

The construction sector worldwide stands as a major consumer of environmental resources and a main contributor to environmental pollution. The building industry accounts for around 45% of society's material consumption. The Green building concept emerged as a possible solution to the negative environmental and climatic problems caused as a result of the greenhouse gas effect. This concept helps to enhance the environment instead of exploiting it. The “green” in this concept refers to the construction and/or design of buildings that seek to safeguard air, water and the environment by making use of materials and construction procedures that are ecologically friendly and cause minimal disruption in the greenhouse gas effect.

Mixed-use buildings are a recent approach in the construction industry that incorporates diverse functions into a single vertical structure. The idea was an innovative response to the challenges of urbanisation aiming to enhance urban design and foster sustainability. A fusion of residential, commercial and cultural elements within the confines of a vertical high-rise structure to create a dynamic and unique multifunctional urban design and environment. This has the advantage of the creation and union of various communities performing a range of activities in a single location, Mixed use buildings have more energy consumption compared to single-use buildings due to the range of activities performed, the occupancy rate and the maintenance of the building facilities. The increasing use of energy has sparked worries about its effects on the environment, availability issues, and resource depletion.

Energy efficiency is often considered in the design and construction of mixed-use high-rise buildings. The nature of these structures demands careful selection of energy-efficient technologies and construction materials. Incorporation of advanced insulation methods, energy-efficient lighting systems, and smart building management systems helps minimize the overall energy consumption of the building. Also, the use of renewable energy sources, such as solar panels or wind turbines, contributes to a more sustainable and resilient energy infrastructure. The implementation of green design concepts not only aligns with environmental goals but also serves to reduce long-term operational costs for both developers and occupants. Passive energy design such as natural ventilation, building orientation, daylighting and others can also be used to increase the energy efficiency of a building.

4.0 Conclusion

Energy-efficient design strategies, such as optimal building orientation and passive design principles, are essential in reducing greenhouse gas emissions and enhancing user comfort in mixed-use high-rise buildings. These strategies create more sustainable urban spaces by decreasing the reliance on energy-intensive systems for heating and cooling.

The integration of renewable energy sources, such as solar panels, is also critical in addressing Nigeria's growing energy demands and limited electricity access. Renewable energy has the potential to improve operational efficiency and sustainability, especially in urban environments where high-rise buildings demand consistent power.

Mixed-use high-rise developments present an effective solution to urbanization challenges by maximizing land use and promoting walkability, contributing to urban sustainability and the creation of vibrant, multifunctional communities. These buildings help alleviate urban sprawl by providing residential, commercial, and recreational spaces within a single structure, encouraging a more sustainable urban form.

Heating, ventilation, and air conditioning (HVAC) systems, along with lighting, are significant contributors to energy consumption in mixed-use buildings. Consequently, energy-efficient HVAC design and sustainable lighting solutions are essential to reduce overall energy usage, lower operational costs, and support environmental goals.

Finally, developing sustainability indicators that reflect the needs of building occupants is critical. Community input is invaluable in aligning the design of mixed-use buildings with sustainability goals and urban resilience, ensuring that these spaces are both livable and adaptive to future environmental and social changes.

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Received: 20-11-2024 / Accepted: 10-12-2024 /Published: 31-03-2025