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A Review Of Effective Energy Utilization And Optimization In Hospital Buildings – Environmental And Economic Benefits

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Abstract:
Background: *Energy is important to modern life, because it is a critical driver for socio-economic development, especially in developing countries like Nigeria. However, it comes at a price to consumers and at an even greater price to the environment, because of environmental pollution caused by fossil fuels used for energy generation. Therefore, this study assessed energy consumption in Nigerian hospital buildings to determine economic and environmental benefits derivable from its effective utilization.*
Materials and Methods: *A systematic review of literature published between 2016 and 2024 on the Scopus and Google scholar platforms was conducted to evaluate the current level of energy audits in Nigerian buildings, present condition of energy conservation programmes and techniques used to optimize energy consumption in Nigerian hospitals.*
Results: *Results revealed there are very few studies about energy audits in Nigerian buildings and they are poorly reported. Majority of the challenges preventing energy conservation in Nigerian buildings are low energy literacy, financial constraints, wasteful consumption attitudes, poor consumer-utility relationships and use of outdated technologies. Adopting solar photovoltaic systems, energy management systems and retrofitting existing hospitals will yield significant energy savings. Energy utilization is beneficial to the environment because it significantly reduces carbon gas emissions into the atmosphere, by providing alternative clean, sustainable and eco-friendly renewable energy sources. Effective energy utilization in hospital buildings reduces average annual consumption by 20% while saving about 500 megawatts per hour.*
Conclusion: *This study concludes that regular hospital energy audits will reveal areas where energy is being wasted and the techniques required for optimizing consumption in the areas. This study recommends using modern technologies for energy audits and educating hospital staff about energy conservation and optimization.*
Keywords: *Energy, Consumption, Audit, Conservation, Optimization, Hospitals*

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I. Introduction

The energy crisis in the world and its consequences for the environment have become a source of worry in recent years, particularly in industries that consume high amounts of energy such as healthcare facilities[1]. A study found out that the energy consumption of hospitals is higher when compared with other buildings like schools and office complexes[2]. Furthermore, another study reported that the energy consumption pattern of hospitals is usually dictated by factors like climatic conditions, type of services being rendered and operational hours[3]. Other factors responsible for high energy consumption mentioned in a similar study are the use of heavy equipment/machineries, high population and occupancy rates and the cyclical nature of work in hospitals[4]. The study equally concluded that modern hospitals consume nearly three times energy per square meter than regular commercial buildings, with some consuming up to four times more energy depending on their operations and location. According to another study, the need to maintain certain environmental conditions necessary for optimal patient care and other daily activities altogether increases operational costs, energy consumption and ultimately affects environmental sustainability[5].

This has aggravated the pressure on hospitals to develop ways of optimizing their energy consumption while also maintaining the highest standards of patient care[3]. The situation in developing countries such as Nigeria is even unique, because most hospitals are usually confronted with inadequate infrastructure, unstable power supply and limited resources for improving energy efficiency[6]. Furthermore, the frequent collapse of the national grid, electricity tariff increase and regular power outages are some of the reasons why many Nigerian hospitals now rely on backup generators, thereby increasing operational costs and environmental pollution. This

was corroborated by the Nigerian Healthcare Facility Survey which revealed that more than 60% of Nigerian hospitals rely on diesel generators as either primary or secondary power source, significantly affecting their running costs and environmental footprint. According to two studies most hospitals in developed countries usually consume between 200-400 kWh/m² yearly, with notable variations across different healthcare delivery models and climatic zones. This high energy consumption is usually caused by the operation of Heating, Ventilation and Air Conditioning (HVAC) systems which are responsible for nearly 60% of total energy use, as well as lighting, medical equipment and other essential services[7,8]. Similarly, another study reported that energy consumption in hospitals cost approximately 5% of the total operating budget, while for some hospitals this cost may run into millions yearly[9]. This is even more worrisome for medical facilities that are always under pressure to efficiently allocate scarce resources across all the aspects of facility management and patient care[10].

More importantly, the World Health Organization (WHO) reported that medical facilities are responsible for contributing at least 4.4% of net global emissions, thereby adding to environmental and climate change problems[11]. Therefore, the need to optimize energy consumption during daily hospital operations, especially in the face of scarce resources and unreliable power supply in Nigerian hospitals has become urgent[12,13]. Furthermore, a related study mentioned that this notable carbon footprint of medical facilities has attracted greater attention from regulatory agencies and environmental protection enthusiasts[14]. However, a study concluded that optimizing energy consumption in hospitals comes with unique challenges because of the critical nature of hospital functions. It is almost impossible for hospitals to just cut down energy consumption without thorough consideration for medical requirements, patient safety and regulatory compliance, like other commercial buildings[1]. Added to these challenges is that the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) have prescribed specific requirements for environmental conditions in medical facilities which must be adhered to, even while pursuing energy optimization strategies[15]. This plethora of challenges has prompted the development of novel technological energy optimization strategies in healthcare facilities by researchers.

Empirical studies by have all recommended workable strategies such as advanced monitoring technologies, building energy management systems and innovative energy-efficient solutions that can provide solutions for reducing energy consumption, without necessarily compromising patient care. These energy optimization strategies according to the studies have the potential of cutting down energy costs of healthcare costs by at least 30% if implemented effectively, resulting in huge financial savings and environmental protection as well[16,17,18,19,20]. Similarly, other researchers have developed numerous analytical tools and models which could bring down the energy costs of hospitals as well. These optimization tools such as the Data Envelopment Analysis (DEA) developed by Charnes, Cooper, and Rhodes (1978) and reported variously could be used to evaluate and benchmark energy efficiency in healthcare facilities[21,22]. According to their respective studies, DEA is a non-parametric method which employs the use of linear programming techniques for evaluating the relative efficiency of decision-making units (DMUs). The application of this tool has become more popular especially in the healthcare sector for the assessment and optimization of energy consumption [7]. Studies have also demonstrated the effectiveness of the tool in determining energy efficiency opportunities, while also benchmarking performance indices. Also, a study applied DEA for the evaluation of the energy efficiency of 45 public hospitals in Malaysia, by determining possible energy savings of 30% through the improvement of operations and upgrading available technology. The study reiterated the advantages of considering service complexity, built area and occupancy rates in assessing energy efficiency[8].

Furthermore, another study examined 23 hospitals in Germany and discovered that the general operation consumption rate for every square meter of the health facility was 0.27MWh; individual bed spaces consumed 23MWh, while the workers in the health care facility consumed 14.37MWh[5]. It is therefore clear from the foregoing that hospitals consume significant amounts of energy and it is possible to optimize this consumption through the use of the appropriate tools and strategies. To this end, this study reviewed the energy consumption and optimization of public hospital buildings to determine the current issues, challenges and possible solutions. This was done by evaluating the principles behind energy audits in buildings, principles of energy conservation in buildings and recent techniques for optimizing energy consumption in buildings, especially hospitals. This is because understanding and improving energy efficiency in buildings and healthcare facilities is essential for developing sustainable healthcare systems that can meet the challenges of the 21st century, while also maintaining the highest standards of patient care.

II. Materials And Methods

This section covers the approach adopted in determining the energy audits of public hospital buildings, the conservation of energy in the buildings and how the consumption patterns could be optimized, to save costs and protect the environment as well. A systematic search of scholarly databases (Scopus and Google Scholar) was carried out to obtain peer reviewed articles. The inclusion criteria were articles which border on energy audits in public buildings, energy conservation in public buildings, energy consumption in hospitals and

optimization of energy consumption in hospitals in Nigeria. The following are the Boolean operators and keywords deployed to aid in the search process: ("public buildings" OR "energy audits in buildings" OR "energy conservation in buildings" AND (Nigeria OR Nigerian public hospitals OR "optimization of energy consumption") AND (environmental protection OR pollution OR net emissions OR patient care OR costs savings OR healthcare facilities OR energy efficiency). The articles identified were subsequently screened for their relevance to challenges and problems facing ineffective energy consumption in Nigerian hospitals. Out of the fifty (50) shortlisted articles, the most relevant thirty five (35) articles containing substantial data needed for this study were selected as shown in Table 1. Therefore, all the articles which did not meet the minimum criteria of describing or addressing the challenges of energy consumption in public buildings, especially public hospitals in Nigeria and were not published between 2016 and 2024 were excluded. These factors served as the exclusion criteria for the study. The review process adopted for this study captured sub-sections such as energy audits in buildings generally, energy conservation in buildings, techniques for energy optimization in buildings, energy optimization in hospital buildings, environmental and economic impacts of energy utilization in hospital buildings.

Table 1: Research works used in the analysis

	Research works	Author(s)
1	The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries	Bakirtas and Akpolat (2018)
2	Energy Efficiency In Public Buildings: The Roadmap To Sustainability In Nigeria	Ukpai and Jude (2023)
3	Energy Consumption Analysis and Characterization of Healthcare Facilities in the United States	Bawaneh*et al.,* (2019)
4	Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply	Kabeyi and Olanrewaju (2022)
5	A Systematic Literature Review on Energy Efficiency Analysis of Building Energy Management	Fang *et al.,* (2024)
6	Nigeria: Solar energy drives greater efficiency at healthcare centers	Kemp (2024)
7	Nigeria's Climate Change Act 2021: A pathway to Net-Zero Carbon Emission, Energy Security and Sustainability	Olujobi (2024)
8	Energy Crisis and Renewable Energy Potentials in Nigeria: A Review	Somoye (2023)
9	Breaking Barriers: Unearthing the Hindrances to Embracing Energy Economics Principles in Nigerian Building Projects	Oke*et al.,* (2024)
10	Nigeria's Energy Deficit: The Challenges and Eco-Friendly Approach in Reducing the Energy Gap	Ndukwu*et al.,* (2020)
11	Energy consumption and Environmental Sustainability: What Lessons for Posterity	Achuo*et al.,* (2022)
12	Review of Renewable Energy in Nigeria for Climate Change Mitigation	Obada*et al.,* (2024)
13	ENERGYSIM: Techniques for Advancing Building Energy Education through Immersive Virtual Reality (VR) Simulation	Anifowose*et al.,* (2023)
14	Building Energy Audit in Nigeria: Some Guides for Energy Efficiency Building Regulations	Mambo and Kebe (2018)
15	Towards Energy Efficient Buildings in Nigeria: Challenges and Opportunities	Ochedi and Taki (2019)
16	Energy Audit in Buildings for Sustainable Economic Development	Kalair*et al.,* (2023)
17	Energy-Saving Strategies on University Campus Buildings: Covenant University as Case Study	Oyedepo*et al.,* (2021)
18	Solar Energy and Its Purpose in Net-Zero Energy Building	Shayan (2020)
19	Analysis of Energy Conservation Factors in Buildings Using Interpretive Structural Modeling Methodology: An Indian Perspective	Qarnain*et al.,* (2020)
20	Effective Techniques for Energy Conservation in Buildings – A Comprehensive Review	Moshi*et al.,* (2021)
21	A Template for Promoting Energy Conservation in Nigeria's Residential Sector	Umoh and Bande (2021)
22	Advances in the Optimization of Energy Use in Buildings	Schito and Lucchi (2023)
23	Energy Efficiency in High-rise Office Buildings: An Appraisal of its Adoption in Lagos	Ezema and Maha (2022)
24	Phase Change Materials for Energy Efficiency in Buildings and Their Use in Mortars	Frigione*et al.,* (2019)
25	The Role of Renewable Energy in the Global Energy Transformation	Gielen and Boshell (2019)
26	Energy audit and Optimal Power Supply for a Commercial Building in Nigeria	Adewale*et al.,* (2018)
27	Walk-Through Energy Audit of an Institutional Building	Atiba*et al.,* (2019)
28	Energy Audit and Efficiency of a Complex Building: A Comprehensive Review	Muhammad *et al.,* (2019)
29	Economic and Environmental Impact of Energy Audit and Efficiency: A Report from a Nigeria Household	Lawal*et al.,* (2024)
30	Analysis of Methodology for Scaling up Building Retrofits: Is There a Role for Virtual Energy Audits?—A First Step in Hawai'i, USA	Glick*et al.,* (2021)
31	Energy Auditing and Conservation for Educational Buildings: A Case Study on Princess Sumaya University for Technology	Mohamed *et al.,* (2022)
32	An Evaluation of Energy Consumption and Conservation Opportunities for	Abdulsalam (2019)

	Buildings at National Institute for Chemical Technology, Zaria	
33	Improving Lighting Energy Efficiency through User Response	Gentile (2022)
34	Optimizing the Performance of Hybrid Renewable Energy Systems to Accelerate a Sustainable Energy Transition in Nigeria: A Case Study of a Rural Healthcare Center in Kano	Yakub*et al.,* (2022)
35	Energy Performance Indices for Hospital Buildings in Nigeria	Nwanya*et al.,* (2016)

Energy Audits in Buildings: Recently, the awareness about energy consumption and use in buildings has evolved tremendously because of the increased need for maintaining sustainability in the environment and efficient energy use as well. According to a study, energy in buildings are all forms of energy consumed during the performance of activities like lighting, cooling and heating, which altogether guarantee the safety, comfort and functionality of the building's occupants[23]. According to another study, the rapid increase in urbanization globally results in a corresponding increase in energy demand of buildings. This effectively creates a pressing need for developing methods that minimize energy consumption, while also maintaining productivity and comfort for occupants[24]. Similarly, several studies reported that the energy consumption of buildings are influenced by factors such as occupant behaviour and climate building design[12,18,24,25,26]. Furthermore, two other studies concluded that the call for sustainable approaches about energy consumption has influenced developed nations to incorporate energy-efficient technologies such as advanced HVAC systems, energy-efficient windows and insulation into building designs to significantly lower energy consumption and reduce the negative effects of climate change on the environment[12,24]. However, other studies conducted also reported that energy efficiency practices in Nigeria are still below expectations and this affects the nation's efforts aimed at achieving the sustainable development goal of combating climate change and entrench clean energy use. Factors responsible for this unimpressive performance are financial constraints, low awareness level and lack of regulatory frameworks[27,28].

Although global frameworks have reiterated the essence of reducing energy consumption in buildings, most developing countries like Nigeria are yet to implement any robust measures that will tackle this growing challenge. Also, similar studies noted that the present energy generation and consumption in Nigeria is not environmentally sustainable considering the unstable nature of the nation's national grid and the fossil fuel used in the process[29,30]. Similarly, a study reported that this has contributed significantly to global warming, while the inadequate effective energy management inherent in the process also wastes scarce resources as well. Furthermore, the critical nature of the energy crisis being experienced globally is reflected obviously in the way energy has been generated and consumed for different purposes such as commercial or residential[31]. For instance, a study argued that buildings constructed for any purpose pose a significant threat to climate action mainly because of their over 40% contribution to global energy consumption and greenhouse gas emission (GHC)[32]. This assertion, supported by another study noted that the over one-third contribution of the building sector to energy use has further increased not just the energy demand and consumption, but has also brought about negative impacts on the global environment[14].

However, another study reported that relevant organizations in the building sector and major cities around the world have begun a campaign towards increasingly adopting energy policies to reduce information asymmetries and knowledge gaps through data transparency, including energy disclosure and mandatory audit requirements for existing buildings and infrastructures. Although such audits impose non-trivial costs on building owners, their energy use impacts have not been empirically evaluated[33]. An in-depth evaluation of energy consumption and habits in buildings is often conducted through an energy audit, particularly in commercial settings to identify areas where energy is being wasted and offer practical solutions to reduce operational costs and improve energy efficiency. According to another study, this is what an energy audit entails, and its processes are systematic, involving checking of energy usage of a specific building, system, or facility to uncover inefficiencies and pinpoint opportunities for future energy savings. The study further argued that this is the first step towards promoting an efficient energy management system and addressing any sources of waste[32].

Energy Conservation in Buildings: Although, financial incentives are major factors, however, the advantages of energy conservation in buildings go beyond immediate cost savings. It helps to promote cleaner water and air, decrease greenhouse gas emissions, while also pushing the country towards renewable energy sources. For example, a study reported that energy conservation methods help to optimize energy efficiency and also greatly improve the performance and well-being of occupants[34]. As such, priority is given to indoor air quality and regardless of the purpose of the building; occupants can become healthier and more comfortable, thereby increasing productivity and overall well-being. Similarly, a study mentioned that among the fundamental principles of energy conservation in buildings is the construction of net-zero energy buildings (NZEBs). This principle, often summarized as "first take up demand, then supply," highlights the importance of implementing energy conservation measures such as efficient lighting, ventilation and using high-efficiency appliances[35]. In

today's world, energy conservation principles have been found to reduce energy consumption, improve sustainability and also mitigate environmental impacts[34,36]. Furthermore, the rising demand for energy-efficient buildings has resulted in the development of various technologies designed to optimize energy use[28,30,36]. For example, a study evaluated solar energy balances in eleven countries by comparing medium efficiency and deep conservation scenarios in various building types and temperature zones for Net Zero Energy Buildings (NZEBs) by 2050[37]. The findings showed that developing regions have better possibility for achieving net-zero energy targets compared with developed nations, because of higher solar energy availability and lower energy consumption patterns. In the deep conservation scenario, many building types in developing regions could reach complete solar coverage for electrical and thermal needs all year round, with the Pacific OECD (PAO) displaying the strongest potential.

The study further reported that high-rise structures like office buildings and multifamily complexes demonstrated lower NZE capability. The medium efficiency scenario (based on current policy trajectories) showed significantly reduced potential for achieving net-zero status, particularly in developed regions. However, some building types such as single-family homes in specific areas maintained full solar coverage potential. Success in attaining NZE status varied by building type, region and scenario, with places like Pacific Asia (PAS) showing potential across all building types, while other regions demonstrated success primarily in low-rise structures like single-family homes and retail buildings. In Nigeria, significant challenges such as behavioural patterns, building economics and technological limitations have significantly influenced the establishment of energy conservation as a national policy, thereby creating a complex web of issues that need to be addressed systematically to improve energy conservation practices in the residential sector. According to two other studies, the difficult relationship between electrical supply companies and consumers characterized by supply-demand accountability issues and inequalities further complicated the energy conservation agenda among stakeholders and policymakers[28,38]. This makes it even more challenging to tackle climate change and reduce fossil fuel burning. Consequently, many consumers are confronted with unfair charges for unstable electricity supply, which discourages them from adopting energy-saving practices. The studies further reported that most Nigerian electricity consumers lack the financial wherewithal to invest in sustainable alternatives like solar panels.

Environmental and Economic Techniques of Energy Optimization in Hospital Buildings: According to a study, buildings generally consume close to 40% of the world's energy and generate about 30% of the CO_2 emissions linked to energy use, underscoring their significant influence on environmental sustainability. This makes energy optimization techniques in buildings an approach the building sector cannot shy away from if the objective of clean energy and environment is to be achieved by 2050[39]. The essence of the practice is to enhance energy efficiency, reduce operational costs and minimize environmental impacts[24,34,38]. In another study which examined optimization strategies used in three different buildings in Lagos, Nigeria, the study revealed that the adoption of energy-efficient strategies remains limited, particularly in the use of renewable energy sources such as photovoltaic, wind, biomass, and geothermal energy, which were found to be unsatisfactory across the evaluated buildings[40]. While the study recognizes the impact of high initial costs, as well as the lack of regulatory incentives as major barriers to the widespread adoption of energy-efficient design and construction techniques in Nigerian high-rise buildings, despite their long-term cost and environmental benefits, the importance of innovative renewable technology integration for nearly zero-energy buildings should not be overlooked.

Another study pointed out that utilizing localized weather data can enable buildings to adjust their energy consumption patterns in response to predicted weather conditions. This proactive approach can lead to energy savings of 15-30% by optimizing thermal and electric loads based on real-time forecasts[41]. Although a similar study suggested a more efficient method in the application of Building Information Modeling (BIM) for energy performance optimization which could best be implemented throughout the lifecycle of the building[42]. The study findings argued that BIM is a tool that can facilitate the design and management of energy-efficient buildings, enabling the integration of innovative technologies such as energy-efficient lighting, HVAC systems, and building-integrated photovoltaics (BIPV) to enhance energy performance and support the development of sustainable building practices. Some of the energy optimization strategies common to buildings in Nigeria are; Renewable energy (solar energy, wind energy, hydro energy, geothermal energy and bio-fuels); Passive design (building orientation, building form, natural ventilation, shading devices, landscaping and thermal insulation); Smart technologies (smart doors, smart lighting and smart HVAC systems); Low energy appliances and reduction of energy waste[40].

III. Results And Discussion

This section covers the results of analyses conducted on the current trends of energy audits in buildings, the principles governing energy conservation in buildings and how well these principles have been

adopted in Nigeria and the prevailing energy optimization techniques in buildings, especially hospital buildings. It also includes the environmental and economic impacts of energy utilization in hospital buildings. The results are discussed accordingly;

Results of Energy Audits in Buildings: In Nigeria, studies relating to energy audits have been few compared to other research areas in the field of building services. The very few studies conducted in Nigeria on energy audits included the studies of [43,44,45,46]. These studies all reported that energy audit (which should be carried out by a qualified specialist) is generally about checking the quantity of energy consumed, the pattern of consumption, identifying inefficiencies and the formulation of actionable recommendations aimed at reducing energy consumption. Furthermore, various methods ranging from traditional in-person assessments to innovative virtual audits could be used to carry out energy audits; each method however comes with its own limitations and advantages. The conventional energy audit includes a thorough evaluation of a building's energy systems, lighting, HVAC and other electrical systems. This process collects data on energy consumption, evaluates the performance of various systems and determines areas where energy savings can be implemented. Also, a study outlined the shortfalls of traditional audits by reporting that many audits carried out even by accredited contractors lack clear reporting. Many of the contractors also make recommendations that do not necessarily contribute to energy savings, thus emphasizing the need for improved methodologies in energy auditing practices[47]. Similarly, another study reiterated the essence of accurately determining energy consumption patterns in public buildings to key into broader sustainability goals, such as the UN 2030 Agenda for Sustainable Development[48]. Furthermore, another study carried out the energy audit of the National Research Institute for Chemical Technology in order to minimize electricity consumption in the facility. The study found that between September 2019 and August 2020, the facility had used around 110MWh of electricity, with air conditioning units accounting for more than 52% of the overall consumption. This outcome reveals the need for energy savings in air-conditioning systems, for more effective energy management[49].

Results of Energy Conservation in Buildings: According to a study, energy conservation in Nigeria's residential areas, the results identified several key challenges confronting the sector. Some of the challenges included; low energy literacy, financial constraints, inefficient consumption behaviours, poor consumer-utility relationships and reliance on outdated technologies. The study also revealed the need to phase out inefficient technologies, increase access to grid-based and renewable energy, and promote affordable energy-efficient appliances[38]. Furthermore, the study identified the enablers for energy conservation including a stable electricity supply, the availability of energy-efficient options, smart metering devices, and policies that incentivize energy-saving behaviours. Similarly, another study has shown that even in the current world of energy consumption, energy-inefficient lighting technologies and appliances remain popular, particularly among low-income populations who cannot afford energy-efficient alternatives like Light Emitting Diode (LED) lamps and Compact Fluorescent Lamps (CFLs)[50]. Also, renewable energy technologies have limited penetration in Nigeria's built environment, often perceived as luxuries accessible only to the elites. The widespread use of diesel and gasoline generators, accounting for approximately 50% of electricity generation with over 14 GW capacities, further complicates the energy conservation landscape in Nigeria.

Results of Energy Optimization in Hospital Buildings: Among the major energy optimization techniques implemented in Nigerian hospital buildings is the adoption of renewable energy sources. The adoption of solar photovoltaic (PV) systems has demonstrated capacity to reduce reliance on diesel generators and the national grid, which are often used as backup power sources in hospitals. Similarly, solar energy systems have also proven to be sustainable solutions in reducing energy costs significantly in the long term. For example, a study examined hybrid renewable energy systems in a rural healthcare center in Kano revealed that optimizing the use of solar energy could greatly lower operational costs and also improve energy reliability[51]. This transition to renewable energy sources recommended in the study is further corroborated by Nigeria's abundant solar resources, making it the most viable alternative for hospitals looking to enhance energy efficiency[34]. Another effective method for optimizing energy consumption in Nigerian hospitals is the institution of energy management systems (EMS). These systems coordinate the control and monitoring of energy consumption in real-time, thereby allowing hospital managers and administrators to ascertain inefficiencies and implement corrective measures[50].

EMS could help enhance energy performance in healthcare facilities, because it encourages better decision-making about energy consumption and also promotes a culture of energy conservation among staff. However, successfully implementing EMS requires proper training for healthcare personnel and willingness to engage in ongoing assessment and improvement of energy practices. Furthermore, building design and retrofitting can also help optimize energy consumption in hospitals. Adopting energy-efficient building designs, such as natural ventilation and passive solar heating, can significantly lower the energy requirements for heating

and cooling[34]. Similarly, retrofitting existing hospital buildings with energy-efficient technologies like high-efficiency HVAC systems and LED lighting can result in significant energy savings. This is also capable of improving comfort for patient and hospital staff, while also reducing operational costs and climate change impacts. Also, the effective management of medical and hospital wastes is an aspect which is often overlooked in terms of hospital energy optimization methods. Effective waste management practices can result in energy savings, through the reduction of energy needed for waste disposal and treatment[9]. For example, incinerating medical waste can be optimized to recover energy and also contribute to the overall energy efficiency of the hospital. However, failing to appropriately train hospital staff in waste management practices and how to comply with regulatory guidelines will prevent the hospital from maximizing the benefits of these techniques.

Environmental Impacts of Energy Utilization in Hospital Buildings: Energy utilization of hospitals ranks as one of the highest among public and commercial buildings; this is attributed to the nature and kind of services rendered[1]. For hospitals to continue to deliver quality healthcare services and also function at optimum capacity, it requires massive energy. However, in many developing countries like Nigeria where energy generation is low and use of renewable energy sources is still at a minimal level, gasoline and diesel-powered generators are utilized as backup energy to address unreliable and erratic power supply[52]. This has led to significant increase in carbon emission and also impacted negatively on the environment. In view of this, recent studies have explored alternative energy sources that are clean, sustainable and eco-friendly[53,54]. In addition, another study suggested that since HVAC systems of hospitals consume the largest chunk of energy, hospitals should find alternative safer sources of energy to power these technologies in order to promote sustainability, improved air quality and safer environment[55]. Also, the use of sustainable energy and more importantly renewable energy sources to power energy intensive equipment like HVAC systems in hospitals in place of fossil fuel-based energy sources will go a long in reducing carbon emissions, release of harmful gases into the atmosphere and more importantly, reduce susceptibility to climate change risks[39,40,56]. In addition, when hospitals redesign their buildings to accommodate green energy, solar energy, solar-powered devices, energy-saving bulbs and also adopt effective waste disposal techniques and technologies, there will be significant reduction in greenhouse gas emissions into the atmosphere[1]. This will further create a clean and safe ambience, which will in turn reduce vulnerability and susceptibility to climate change risks.

Economic Impacts of Energy Utilization in Hospital Buildings: One of the major concerns for stakeholders in the healthcare sector is finding suitable energy efficiency technologies that will not affect productivity. Still, there persists a growing concern that energy optimization may prevent hospitals from performing their functions at optimum capacity. Energy management in hospitals requires special attention and monitoring from hospital's management team[1]. A study suggested different energy-saving methods that can be adopted by management team of hospitals; these are adequate maintenance and regular monitoring of energy consumption. The study posits that this method is capable of reducing average annual energy consumption by 20%, while saving about 500 megawatts per hour (MWh)[12]. In addition, the report noted that this method will not only significantly reduce greenhouse gas emissions but will help to save about 75,000 Euros annually on the average. Studies have also advocated for hospitals to use alternative water sources which are cost effective and also save energy[20,24]. A good example of alternative water source suggested is desalination water plants that do not require as much energy as the conventional water treatment plant in hospitals. Another cost-effective method that can be adopted by hospitals is the use of renewable energy like solar energy for day to day activities[56].

IV. Conclusion

This study carried out the assessment and optimization of energy consumption in public buildings, especially public hospitals in Nigeria. This was done through the review of relevant literature and results were outlined. Based on the results obtained from the analyses of energy audits, review of energy conservation in buildings and energy consumption and optimization in hospital buildings, the following conclusions is drawn;

i) Only few studies have investigated energy audits in Nigerian buildings through in-person assessments and innovative virtual audits, thereby creating a clear research gap. However, the few traditional in-person audits conducted lack clear reporting and they also suggest recommendations that do not contribute to energy savings in the buildings investigated
ii) Some of the factors confronting energy conservation programmes in Nigerian buildings are; low energy literacy, financial constraints, inefficient consumption behaviours, poor consumer-utility relationships, and reliance on outdated technologies. This is because the low-income population (the highest demographic) in Nigeria cannot afford the energy-efficient technologies that promote energy conservation
iii) Adopting recent technologies such as solar photovoltaic systems and energy management systems, while also retrofitting existing hospital buildings with energy-efficient technologies like high-efficiency HVAC

systems and LED lighting can result in significant energy savings. This will also result in the optimization of energy consumption in the hospitals.

iv) Energy efficiency as well as optimization in hospitals is achievable without compromising standards, productivity or putting lives of patients at risk. This is beneficial to the environment as well as cost-effective and economical. Hospital managers are therefore encouraged to adopt some of the energy optimization methods suggested in the literatures reviewed.

Based on the foregoing conclusions, the following recommendations are made;

i) The creation of a culture of energy awareness among hospital staff is highly important for the successful design and implementation of energy optimization methods

ii) Conducting training programmes that will teach hospital workers about the importance of energy conservation and how to optimize energy consumption can lead to significant behavioural changes

iii) Engaging hospital staff in energy-saving programmes will also ensure that optimization techniques are highly effective and will also promote a sense of ownership and responsibility towards energy management within the hospital.

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