Exploring the Application of Internet of Things (IoT) For Energy Efficient Buildings in Nigeria. A Review

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Abstract

The global adoption of smart building technologies has been facilitated by the present shift toward Internet of Things (IoT). Despite its benefits, its adoption is still relatively low in developing nations like Nigeria. Therefore, this paper aims to investigate the application of IoT for greatest energy efficiency in buildings, with a greater focus on Nigeria. A review of relevant literature was carried out, to identify the application of IoT in buildings, the current state of IoT application in the Nigerian built environment sector, characteristics and current practices of Nigerian residential buildings regarding energy consumption patterns. A total of 60 papers were reviewed using a narrative and content analysis method. This paper highlights; the lack of smart sustainable building construction in Nigerian and explores the application of IoT for monitoring and visualising the performance of buildings in Nigeria with the aim of optimising efficiency in energy usage. The review has identified research gaps and potentials which can be explored further.

Keywords

Energy efficient buildings, IoT (Internet of Things), Nigeria, Residential Buildings, Sustainable construction, Smart buildings.

1. Introduction

Rapid digitalization has created enormous issues that have raised the energy need (Al-Obaidi et al., 2022). The new era of digitalisation creates new opportunities to boost energy efficiency in the built environment, human health and productivity. One of these opportunities to reduce energy use and accomplish sustainable development goals is the Internet of Things (IoT) (Casini, 2014). When the terms "internet" and "things" are combined, an information and communication technology (ICT) innovation is communicated (Al-Obaidi et al., 2022). Everyday physical items may easily integrate electronics into any form of global physical infrastructure thanks to the concept of interconnected objects (Shammar & Zahary, 2020).

IoT could allow seamless interaction between devices and appliances in intelligent setting, with or without human intervention (Karthick et al., 2021). IoT-connected devices play a crucial role in data collection, processing, and analysis creating a wealth of opportunities for monitoring, managing and improving energy use efficiency in any system (Hakimi et al., 2020). Adopting intelligent IoT technologies can provide network connectivity through which information and services related to physical devices can be exchanged (Al-Obaidi et al., 2022). This may further underline the potential of IoT for preserving energy within the context of buildings. IoT in the built environment is mainly employed to work with data via collection, transmission, storage and analysis (Ashraf, 2021).

IoT applications in smart buildings are growing increasingly popular recently, according to research, as a means to boost energy efficiency and reduce environmental effects (Kumar et al., 2022). Researchers have been drawn to examine IoT and energy efficiency measures because of the profiling of energy consumption in buildings (Xu et al., 2020). Furthermore, the trend towards merging smart buildings with modern detection techniques has begun to provide the groundwork for seeing IoT as an essential component of smart cities (Al-Obaidi et al., 2022). Other studies found that if buildings prioritize excellent system communication, they might consume much less energy (Ceranic et al., 2018; Yahiaoui, 2018). As a result of the advancement in networking, computing, and sensing technologies, the Internet of Things has become an integral part of the design and operation of every intelligent device in the built environment (Ashraf, 2021; Plageras et al., 2018).

Despite the benefits and widespread existence of IoT in numerous fields and construction, little research has been done to investigate the adoption of IoT in construction, particularly in developing nations (Chen et al., 2020). Oke et al. (2020) stated that Nigeria is still lagging in technological advancement because IoT is not extensively employed in the construction industry. To address the enormous environmental challenges and economic concerns that have stifled progressive growth in Nigerian construction, it is clear that adopting smart building technology is critical for development in order to boost innovation and competitiveness (Ejidike et al., 2022). Therefore, this paper aims to investigate the application of IoT (Internet of Things) for the energy efficiency of buildings with a focus on Nigeria. The goal is to highlight the need for IoT application in the Nigerian built environment with the aim proposed.

The study was made to understand, through a general review of the current application of IoT in buildings globally. The paper presents findings from this review on the current state of IoT application in the Nigerian built environment sector, current building style and characteristics of the Nigerian building stock. Furthermore, the study shows recent energy consumption patterns of residential buildings in Nigeria. The research questions addressed are as follows;

RQ1; What are the current trends of IoT application in Buildings globally?

RQ2; What is the current state of IoT application in the Nigerian built environment?

RQ3; What is the current building style and characteristics of Nigerian Buildings?

RQ4; What are the current energy consumption patterns in Nigerian Residential Buildings?

2. Methodology

Grant and Booth (2009) highlighted four common methods of reviewing literature; narrative, rapid, scoping and systematic. The method adopted in this paper is a traditional (narrative) review which identifies what has been accomplished previously, allowing for consolidation, building on previous work, summation, avoiding duplication and identifying omissions or gaps (Grant and Booth, 2009) and makes use of content analysis to examine current trends. According to Stemler (2001) content analysis is useful when looking for trends and patterns in documents. Secondary data was used to perform this study, which is information gathered by someone else for a main purpose (Johnston, 2014). Secondary data gathering and analysis use less time and resources than original data collection and analysis (Johnston, 2014). Secondary information such as publications and journal articles were sourced through scientific databases like; Elsevier Scopus, Google scholar, IEEE and Emerald. The search used the keywords of IOT, sustainable construction, smart buildings, energy efficiency and residential buildings" and Affiliation Country of "Nigeria" were used as prompts in finding literature. 150 papers were identified and scrutinized, but later reduced to 60 papers. By a careful review to eliminate duplicate entries (i.e., referring to the same document), incomplete/incorrect bibliographic details and to exclude non-scholarly/non-peer-reviewed materials.

3. Result and Discussion

3.1 IOT in Buildings.

Balikhina et al. (2018) used the Amazon Web Service IoT platform to create and execute a system architecture for smart power meters to monitor and regulate energy use in residential buildings more effectively. Govindraj et al. (2018) presented an IoT-based management system that links household appliances through the internet and allows customers to operate appliances from any location and at any time using a smart phone. In Marinakis and Doukas (2018) work, an Intelligent energy management in residential settings was proposed via connections between buildings and IoT systems. The system collects and analyses building energy data, then presents the studied data to building occupants in real time. Amaxilatis et al. (2017) developed an IoT based solution to monitor energy usage in educational offices to enhance energy efficiency and human productivity. Luo et al. (2019) proposed that the combination of big data and IoT can be used in energy management systems of office buildings. Rafsanjani and Ghahramani (2019) highlighted a real-time dynamic link between IoT infrastructure information and office-building occupancy-related energy-use trends. Li et al. (2020) used IoT with a solar water heating (SWH) system to improve energy efficiency in a building. The research was carried out at a Singaporean hospital to demonstrate IoT efficiency by monitoring solar levels, operational schedule, water flow, and power consumption. The study found that the SWH with simultaneous control can save electricity by up to 32.9%.

3.2 The Current State of IoT Application in the Nigerian Built Environment.

Nigeria is in West Africa and is bounded to the north by Niger, to the west by Benin, to the east by Cameroon, to the northeast by Chad, and to the south by the Atlantic Ocean. It is between latitude 4 degrees north and 14 degrees north of the equator and longitudinal 3 degrees east and 15 degrees east of the Greenwich meridian (National Commission for Mass Literacy, Adult and Non-Formal Education (NMEC), 2008). It has a land size of 923,768 square kilometers (Aliyu et al., 2018). Nigeria is the most populous country (around 200 million persons) and the largest economy in Africa (International Energy Agency (IEA) et al., 2019). The Nigerian construction industry's interest in smart buildings has risen dramatically because of technological advancement and the need for increased productivity, efficient energy management and good indoor air quality (Oyewole et al., 2019). Integrating smart building technology into the Nigerian construction sector is crucial, particularly in developing nations dealing with security challenges (Oyewole et al., 2019). Several advantages have been associated with the integration of smart technologies in the Nigerian building sector. For instance, Bandara et al. (2019) indicated that the most prominent benefits of implementing smart building technology are energy conservation, enhanced system performance, life and property security, and occupant health and productivity.

Information on professional awareness for smart buildings is useful in overcoming numerous constraints to smart building techniques in Nigeria. However, there are substantial barriers to the development and investment in smart buildings, particularly in Nigeria and other developing nations. Perhaps, the most significant barrier is the lack of awareness and expertise about smart building concepts (SBCs) in Nigeria (Ejidike et al., 2022). Few researchers have worked on SBCs, while others have focused on building automation, intelligent building, and smart building characteristics in the Nigerian construction sector. Makarfi (2015) in his research, assessed the level of awareness of intelligent buildings among Nigerian architects in the Kaduna metropolitan area and discovered that the awareness of intelligent buildings is lacking among these professionals. In Ogunde et al. (2018) investigation of the integration of building automation systems in Nigerian houses, they revealed a lack of understanding among construction experts, a vital component of SBCs. Oyewole et al. (2019) study looked at smart building awareness and residents' desire for smart building features. They discovered a high level of awareness of smart buildings, with security and safety aspects being the most requested.

Nigerians, the States and Federal Government of Nigeria are uninterested in the modern technology that is taking over every aspect of the life of the citizens in other developed countries (Ayeni, 2020). It is evident that in order for IoT solutions to be deployed across Nigeria, significant improvements to our critical physical infrastructure, such as power and telecommunications, as well as careful amendments to the relevant institutional infrastructure, such as existing regulations respecting data accessibility, security, privacy, anonymity, spectrum licensing, interoperability, and infrastructure improvements, must be carried out by all IoT stakeholders (Uzoma et al., 2021).

Already, governmental and corporate entities in Nigeria are working to develop IoT and provide the groundwork for its adoption. Some of these efforts could be seen in the following initiatives: Indigenous firms such as GRIT systems, Fasmicro and iHabitat manufacture IoT products and solutions (Okunola, 2018). Through the National Information Technology Development Agency (NITDA) and in partnership with Cisco Systems, the federal government built and equipped six IoT laboratories in six federal universities across the countries six geopolitical zones (Uzoma et al., 2021). Nonetheless, Okunola (2018) stated that Nigeria's IoT sector continues to lag behind those of other African nations such as South Africa and Kenya. This was corroborated by Chukwudebe et al. (2021) who stated that as of 2018, the IoT segment of Nigeria's technological sector was underperforming in comparison to other African markets like Kenya, South Africa, Egypt. Therefore, there is an urgent need to speed up IoT development so that Nigeria will assume a leading role in Africa.

3.3 The Current Building Style and Characteristics of the Nigerian Building Stock.

Nigeria faces a severe shortage of housing stock with up to 16 million of housing deficit (Gesellschaft für Internationale Zusammenarbeit & Nigerian Energy Support Programme (GIZ & NESP), 2014). Rural-urban migration leads to extensive urbanisation, which adds to Nigeria's massive housing deficit (Geissler et al., 2018). It is paramount to provide adequate housing for the masses. Nonetheless, it is apparent that construction activities will undoubtedly put additional strain on the existing energy supply system in the absence of effective regulations promoting energy efficiency and localized renewable energy consumption (Gesellschaft für Internationale Zusammenarbeit & Nigerian Energy Support Programme (GIZ & NESP), 2015). Despite fluctuating or even failing grid energy supply and fuel scarcity, it has been observed that new buildings are largely designed in accordance with what is known as "international style of architecture" (Geissler et al., 2018).

There appears to be a general lack of understanding in Nigeria regarding the direct relationship between building designs and technologies, and their influence on energy efficiency in cutting-edge building design (Geissler et al., 2018). GIZ and NESP (2015) indicated that the approaches for developing energy-efficient buildings are beyond the skills and expertise of majority of architects in Nigeria. Traditional building materials and concepts responding to local climatic conditions are usually considered unprogressive. In contrast, modern materials and building designs from abroad are preferred, leading to designs that consume a large amount of energy, especially for cooling and lighting (GIZ & NESP, 2014). Even though there are a few well-tested and sophisticated solutions available that would fit the climate (e.g., usage of phase change materials, activation of thermal mass), these measures are not well established due to a lack of local precedent (Geissler et al., 2018). Building energy efficiency is a novel idea in Nigeria. To confirm this, the first Building Energy Efficiency Guide (BEEG) for Nigerians was published in 2016, and the Nigerian Building Energy Efficiency Code (BEEC) was introduced in August 2017. As a result, little or no effort has been made in the Nigerian building sector to make building designs more energy efficient. Therefore, incorporating energy-saving techniques in subsequent housing interventions will surely improve people's well-being and the human environment (Ochedi & Taki, 2022).

Assessment of the status quo relies on experts' opinions, case study analyses, and general observations, because neither systematic data collection on the technical characteristics of the building stock nor statistics on actual power usage connected to building types are available (Geissler et al., 2018). There are additional issues affecting baseline data assessment: the existence of suppressed energy demand, electricity theft, and the fact that private generators take over in the event of grid failure (Adamu et al., 2020; Dioha & Emodi, 2019). In Nigeria, the difficulty to acquire data for policy and investment planning is a potentially major issue, as is the practice of so-called estimated billing (households are charged based on estimates rather than actual use due to the lack of meters) (Olaniyan et al., 2018). Olanrewaju and Adegun (2021) corroborated this by saying that among households with electricity connections, tracking residential electricity use is frequently difficult due to privacy issues and the challenge of unmetered households—residences that utilise public utility electricity but have malfunctioning or no meters to record consumption for billing purposes.

3.4 Residential Building Energy Consumption Pattern in Nigeria.

Energy access has been highlighted as the "missing development objective," and its role in supporting economic growth, decreasing poverty, expanding educational reach, and enhancing health has been investigated (Bazilian et al., 2012; Groh, 2014). Energy consumption patterns in Nigeria's economy can be classified as industrial, transportation, commercial, agricultural and residential (Energy Commision of Nigeria (ECN), 2018). The residential sector is critical for the design of sustainable energy systems in developing nations, since it accounts for more than a quarter of non-OECD countries' ultimate electricity consumption, and even up to 60% in countries such as Nigeria (International Energy Agency (IEA), 2017). Also, the expansion of the service sector on the one hand and the rising demand for energy services such as refrigeration, lighting, and cooling in the residential sector on the other hand, urbanisation has led to higher power consumption in residential buildings (Geissler et al., 2018).

The demand for residential electricity in Nigeria grew by roughly 30% (IEA, 2017). This energy is usually consumed in the form of kerosene, liquefied petroleum gas (LPG), electricity and biomass (Energy Commision of Nigeria (ECN), 2014). Nigeria households' main energy service requirements are cooking, lighting, refrigeration, air conditioning, water heating and other electrical appliances such as fans and audio-visuals. Lighting energy requirement in Nigeria households is mainly satisfied by electricity and kerosene. The electrified households concentrated in the urban areas use electricity and the non-electrified households mostly found in the rural areas depend on kerosene for lighting (Dioha, 2018). Other sources of lighting like firewood, candles and dry cell battery torches are also used most especially in the rural areas. However, urban dwellers sometimes resort to kerosene lanterns and dry cell battery torches during blackouts, which is quite common in the country (National Bureau of Statistics (NBS), 2012). The technologies employed for electric lighting are inefficient incandescent bulbs, compact fluorescent lamps (CFLs) and light-emitting diode (LED) bulbs (Dioha, 2018).

Air conditioning and refrigeration services are mostly concentrated in urban areas and energy requirements are completely satisfied by electricity. Most of the air conditioners and refrigerators in use are inefficient types and they are very old. Household cooking takes up to 91% of household energy (Dioha & Emodi, 2019). A survey conducted in urban South-West Nigeria found that the main fuel used for cooking is kerosene (about 90% of the households) while electricity and LPG are used minimally (Ajayi, 2018) mostly in urban areas. The technologies employed in cooking are usually the inefficient traditional three-stone stove system for burning fuelwood, kerosene, and LPG stoves. The continual reliance on fuelwood has led to the clearing of many forests in the country, contributing to climate change (Dioha, 2018). Also, the pollution resulting from burning of biomass for cooking leads to respiratory diseases and has been responsible for about 79000 deaths annually in Nigeria (World Health Organization (WHO), 2007). Most of the rural dwellers find it extremely easy to collect firewood for cooking since it is readily available at no cost.

Water heating is another energy service that consumes a significant amount of energy in the Nigeria household sector (Dioha, 2018). Nigeria has a tropical equatorial climate that is hot for most of the year. Hence only a few people; most especially those in the urban areas use hot water for bathing (Dioha, 2018). The technology commonly used for water heating in Nigeria households is the electric kettle which is concentrated in the electrified urban areas. Many rural dwellers and non-electrified urban dwellers satisfy their hot water needs with the same technologies for cooking (Ezema et al., 2016). Other residential appliances such as ceiling fans, radio, and television consume significant amounts of energy and are mainly inefficient types (Energy Commision of Nigeria (ECN) et al., 2013). These electrical appliances are usually owned by electrified households (Dioha & Emodi, 2019). Ownership also depends on income as this can be observed in the urban-rural ownership dichotomy in the country (Dioha, 2018).

4. Gap and Future Research Direction

Gap No.1*:* Al-Obaidi et al. (2022) undertook a study with the aim of providing an extensive review of IoT applications for energy savings in buildings and cities, they highlighted the fact recent studies deployed IoT sensors or IoT-based prototype systems for both building monitoring and visualising associated data contributing toward energy efficiency and users or facility managers' adaptive responses to save energy. The context of the studies includes the USA, Europe, UK, India, Korea, China, Mexico, Canada, Turkey and Taiwan with certain types of climates. Given the growth and use of IoT technology, the research found a lack of sufficient studies on IoT applications for monitoring and visualising building performance throughout the rest of the world. Chen et al. (2020) claimed in their submission that the readiness of practitioners in the construction sector of developing countries to incorporate IoT applications was not particularly noteworthy. Smart building technology adoption is crucial to tackling the significant problem associated with the low rate of productivity, delay in construction time, inadequate awareness of technological advances and environmental challenges that impede growth in developing nations (Adeosun & Oke, 2022; Indrawati et al., 2017; Oyewole et al., 2019).

Gap No.2*:* Ogidiaka et al. (2017) stated that in Nigeria, the usage of the IoT in different organizations revealed the non-existence of IoT in research, planning and early stages of adoption despite the potential to utilise it. Nigeria still struggles with the infrastructure and innovation gap, not to mention maximising the emerging technologies in providing services like other developed countries (United Nations, 2015; Hajduk, 2016). Ejidike et al. (2022) in his study concluded that construction professionals still need more effort to increase the awareness of smart buildings in the construction industry to deepen the practices in a Nigerian context. They went further to state that the increase in the awareness and adoption of smart building construction would further improve energy efficiency, thereby saving energy costs and protecting the environment from harmful greenhouse gases, protecting lives and property by installing a smart security system that monitors buildings.

Therefore, an empirical study is required to highlight the application of IoT for monitoring and visualising the performance of buildings in Nigeria with the aim of optimising energy efficiency. A critical evaluation to the development of an IOT implementation framework for Nigerian Buildings will form the next stage of an on-going research by the authors.

5. Conclusions

The aim of this study was to investigate the application of IoT (Internet of Things) for the energy efficiency of buildings with a focus on Nigeria. This paper exposed the current trend of IoT applications in buildings globally, current state of IoT application in the Nigerian built environment, current building style and characteristics of the Nigerian building stock, residential energy consumption patterns in Nigeria and the gaps and future research direction.

The review established the growth of IoT in recent years, its benefits and applications to the built environment globally. However, its adoption in developing countries, primarily Nigeria is still lagging in technological advancement because IoT is not widely used in the construction industry.

Therefore, with the aim of achieving improved environmental conditions and mitigating economic barriers that have stood in the way of development within the Nigerian construction sector, it is evident that implementing the practice of IoT in the construction sector more often than before becomes a crucial step to be taken. These technologies show a more advanced approach to energy-efficient usage, which can help the stakeholders of construction projects produce better outcomes regarding its design and operation.

This research is expected to benefit every stakeholder who has a connection with the construction industry, primarily in Nigeria and other developing countries and educators focused on built environment subjects.

The study was limited to academic journal articles and publications sourced from scientific databases described. The analysis and discussions were done solely on secondary data. However, the utilisation of primary data could have produced a far more in-depth understanding of the subject.

For future research, given the rapid evolution of IoT and its applications in the built environment, it would be good to compare the information presented in this study to other future studies on the same issue. Moreover, it is recommended that primary data collection via case studies and questionnaires for a more in-depth analysis could bring solutions that may lead to significant changes and improvements to the technological device and its adoption in the Nigerian built environment.

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