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A study of smart technologies on energy consumption and efficiency in urban environments

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Abstract
The effects of urbanization on the environment, especially with regard to energy use, are one of the main worries. The density of population and commercial activity in urban areas greatly increases the need for energy. Global greenhouse gas emissions are continuously growing on a global scale. Buildings are responsible for about 40% of the overall end-use energy consumption and have a higher share when compared to other global end-use energy sectors (industry and transportation). Smart technologies provide the means to monitor, control, and adapt energy systems in real-time, enabling more informed decision-making and resource allocation. This research paper delves into the transformative impact of smart technologies on energy consumption and efficiency within urban environments. As global urbanization trends continue to accelerate, cities face escalating challenges related to energy demand and resource optimization. The study investigates the role of smart technologies in addressing these challenges. Through a comprehensive literature review, the research explores the implementation and effectiveness of smart technologies in urban settings. Building systems may now independently integrate surplus data from IoT devices and tenant behaviour to improve environmental effectiveness, streamline workflows, and provide new insights thanks to artificial intelligence. The learning capabilities of IoT and AI platforms enable the development of creative new services for communication with building occupants. Smart buildings seek to maximize industry 4.0 which makes it more efficient and environmentally sustainable.

Keywords: Energy consumption, energy efficiency, smart buildings, technology, urbanization

Introduction

Global urbanization trends have witnessed a remarkable surge in recent decades, reshaping the demographic landscape and presenting both opportunities and challenges for societies worldwide. The rapid pace of urbanization is attributed to factors such as rural-to-urban migration, natural population growth, and economic development, which often concentrates in urban centres (Guo & Qiao, 2020) [12]. This phenomenon is particularly pronounced in regions like Asia and Africa, where cities are experiencing unprecedented population growth and infrastructural expansion (Wei *et al*., 2023) [37]. As cities continue to evolve and expand, the implications of global urbanization extend beyond sheer population numbers. Urban areas serve as hubs for innovation, economic development, and cultural exchange, attracting diverse populations seeking improved living standards and employment opportunities. However, the burgeoning urban population also strains existing infrastructure, exacerbates issues of congestion, and places significant demands on resources, including energy and housing (Akhtar & Ali, 2023; Haque *et al*., 2019) [6, 13]. Such challenges highlight the need for holistic approaches to urban planning and management to ensure sustainable and resilient cities for the future. 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, 2023) [4].

One of the critical concerns associated with global urbanization is the environmental impact, particularly in terms of energy consumption. The concentration of people and economic activities in cities contributes significantly to energy demands (Sodiq *et al*., 2019) [34]. Smart technologies have emerged as potential solutions to address this issue, offering opportunities for enhanced energy efficiency, resource optimization, and improved quality of life in urban environments (Nižetić *et al*., 2019) [28]. These technologies encompass a range of innovations, from smart grids and energy- efficient buildings to the integration of Internet of Things (IoT) devices for real-time monitoring and management.

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) [3]. Urban areas face a myriad of challenges concerning energy consumption and efficiency, stemming from the complex interplay of factors associated with rapid urbanization. The concentration of industries, commercial establishments, and residential complexes intensifies the need for electricity, heating, and cooling, placing a strain on existing energy infrastructure. This heightened demand not only contributes to the depletion of conventional energy sources but also exacerbates the environmental impact through increased emissions and pollution (Abbasi *et al*., 2021; Nazir *et al*., 2020) [1, 27]. At current estimates, global energy related greenhouse gas (GHG) emissions are expected to double by 2050 heightened by an increased oil demand, apprehensions over security of future supplies and energy consumption (Isa *et al*., 2016) [16]. As a result, the innovative strategies such as novel transport, renewable energy, carbon capture and storage (CCS) technologies are urgently required to effectively reduce GHG emissions. In addition, global patterns in energy consumption and climate trajectories will require the deployment of energy-efficient, sustainable materials or zero carbon energy technologies particularly for heating and cooling in buildings Outdated and inefficient urban infrastructure compounds the challenges associated with energy demand. Moreso, the growing population consequent of urbanization has varying effects on domestic solid waste generation and if it is not well managed the residents' well-being is endangered (Onamade *et al*., 2022) [3]. Many cities grapple with aging buildings, inadequate public transportation systems, and inefficient energy grids. These outdated structures not only contribute to higher energy consumption but also hinder the implementation of modern, sustainable technologies. Smart technologies have emerged as powerful tools in transforming the landscape of energy consumption and efficiency, providing innovative solutions to address the complex challenges of sustainability and resource optimization (O'Dwyer *et al*., 2019) [29]. Smart buildings offer great comfort and increase safety for building occupants, improve energy efficiency, and lower facility running costs via automation, sensors, and remote features. Smart buildings deploy IoT sensors to detect and analyze several factors in building parameters that can be used to improve buildings' environments and activities. Smart buildings, which use the Internet of Things (IoT) to connect building operations, and monitor building temperature, security, and maintenance, are easier to control via smartphones and tablets (Tyagi, 2019) [35]. Buildings are becoming smarter due to the IoT, which is capable of integrating thousands of sensors and enabling real-time data collecting and analysis, making them more efficient and user-friendly (S. F. A. Shah *et al*., 2022) [33].

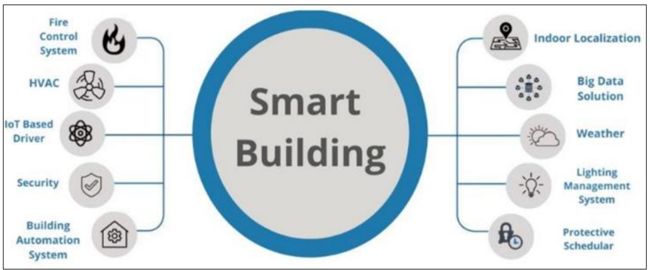
Literature Review

Global greenhouse gas emissions are continuously growing on a global scale. Buildings are responsible for about 40% of the overall end-use energy consumption and have a higher share when compared to other global end-use energy sectors (industry and transportation) (Malla & Timilsina, 2019) [22]. The residential building sector usually consumes more energy than the commercial sector. Most of the energy demands in the residential sector are related to space heating and hot water preparation, while it is primarily HVAC systems and lighting in the commercial sector. Buildings are identified as severe pollutants with a share of CO2 emissions ranging from 30% to 40%, depending on the specific economy (Huo *et al*., 2020) [15]. Besides CO2 emissions, buildings are also responsible for other impacts on the environment, mostly air and water- based pollution caused by cement plants (Mehra *et al*., 2022) [25]. According to the projections of heating, cooling and hot water preparation demands, a rising trend is expected and mainly in the residential sector (Castaño-Rosa *et al*., 2021) [7]. The residential sector will be especially affected with a significant rise in cooling demands due to global warming issues in upcoming years (Santamouris & Vasilakopoulou, 2021) [31].

Internet of Things (IoT) devices equipped with sensors play a pivotal role in this transformation by enabling real-time monitoring of energy usage (Hossein Motlagh *et al*., 2020) [14]. From smart meters that offer detailed insights into electricity consumption patterns to sophisticated sensors embedded in appliances and industrial equipment, these technologies empower consumers and businesses with actionable data to make informed decisions about their energy use. The granular data provided by IoT devices facilitates not only more efficient resource allocation but also the identification of opportunities for energy savings and optimization. Machine learning can be used to automate a wide range of tasks. Smart buildings, which use the Internet of Things (IoT) to connect building operations, enable activities, such as monitoring temperature, safety, and maintenance, for easier controlling via mobile devices and computers (S. F. A. Shah *et al*., 2022) [33]. Smart buildings are becoming core aspects in larger system integrations as the IoT is becoming increasingly widespread. The IoT consists of a collection of connected physical objects that are linked together by sensors, applications, and other technologies for data integration and exchange across devices and systems.

The goal of the Internet of Things is to have devices that can self-report data and information regularly, enhancing efficiency and delivering essential information speedier than a system that is based on human input (S. F. A. Shah *et al*., 2022) [33]. Smart buildings use connected technologies, devices, data analytics, and automation to control infrastructures, such as security, lighting, ventilation, heating, and air conditioning (Vijayan *et al*., 2020) [36]. Smart heating, ventilation, and air conditioning (HVAC) controls can reduce HVAC usage, especially during peak energy demand periods, by limiting power consumption in unoccupied building zones, detecting and diagnosing issues, and limiting energy consumption. Smart lighting uses modern controls to eliminate over lighting by including day lighting and improved functions for detecting occupancy and dimming. Light level controllers for luminaries are rapidly evolving and gaining adoption throughout the industry. Step and continuous dimming control are rewarded in demand-response schemes. Lighting management systems can be programmed to regulate smart lighting systems that are controlled wirelessly (Khoa *et al*., 2020) [18]. Retrofitting is made easier with wireless controllers, while lighting management capabilities provide users with access to controls through web-based dashboards.

Smart buildings can be made safer and much more secure via the application of careful planning, capable management, and sensible regulations. To achieve energy efficiency enhancement, the very first step is to identify the important parameters involved in the issue, this is followed by the formation of appropriate algorithms for processing the data and information that has been obtained based on the history and results of forecasting analytics of how energy is absorbed in smart buildings. People can feel safe and comfortable in smart buildings with the integration of AI and IoT. Data from a range of sensors are used by IoT-enabled smart buildings to reduce energy consumption and increase operational efficiency (Li *et al*., 2021). IoT devices installed in smart buildings help smart buildings to control their energy consumption (A. S. Shah *et al*., 2019). The Internet of Things (IoT) detects and analyzes environmental impacts, such as humidity, temperature, and pressure, to reduce energy consumption in smart buildings. Smart buildings use IoT sensors to regulate and manage lighting by turning them on and off as needed. Emergency management and reaction can be improved with the usage of IoT technologies, resulting in considerably improved results. By connecting sensors and sending real-time information to managers, rescuers, and endangered people, the Internet of Things (IoT) has transformed our perspective regarding safety mechanisms (S. F. A. Shah *et al*., 2022) [33].



Source: (S. F. A. Shah *et al*., 2022) [33]

Fig 1.1: AI-based systems for smart buildings.

I. Building automation systems (BAS)

Building automation systems (BAS) are intelligent systems that aim to automate the management of multiple control functions and increase resources. Scalability issues include not just adding additional devices, but also managing them, as well as guaranteeing consistent and robust communication (Ahmad & Mir, 2021) [5]. When comparing different IoT solutions, the amount of time it takes to install each sensor correlates directly to the entire cost (Chung *et al*., 2023) [8]. BAS keep an eye on each utility's performance and potential problems and notify the building's managers if anything goes wrong.

ii. **IoT indoor localization**

An IoT indoor localization algorithm that determines the position of things must be hybrid. A hybrid algorithm is a problem-solving algorithm that incorporates two or more different algorithms. Sensor-based indoor tracking and placement are frequently required in evolving IoT applications, and efficiency is considerably improved by detecting the nature of the nearby indoor environment (Farahsari *et al*., 2022) [10].

iii. Lighting Management System

IoT-based lighting control is essential for smart buildings, to provide lighting control in buildings, and a range of vendor-specific approaches and technologies have been implemented. Visible light communications (VLC) solutions, which will become available in the next several years, are another breakthrough in Internet of Things (IoT) adoption (Matheus *et al*., 2019) [24]. Infrared transmission has been employed in systems (both outside and indoors the former is based on free- space optical communication systems). Most people presume that visible light from LEDs is included in VLC (T.-C. Yu *et al*., 2021) [38].

iv. Protective Schedulers

Smart plug load controls are receptacles and power strips that automatically turn off power to equipment that can detect the major load, such as a computer, and adjust the operation of peripheral devices appropriately. Plug load schedules can be incorporated into lighting and buildings' management systems (BMS) for centralized control (Zafar *et al*., 2020) [40].

v. Large Amounts of Data

Different businesses face basic challenges in integrating and sharing large amounts of data. Traditional databases are merged with big data databases to generate meaningful results. Big data exchange among consumers, on the other hand, is seen as a major difficulty (Marinakis, 2020) [23]. Furthermore, big data raises serious challenges, such as data privacy and security. The IoT with AI offers solutions to these problems, as IoT is being integrated into decentralized energy systems to enhance the environment by increasing energy efficiency and reducing waste (Kumar *et al*., 2020) [19].

vi. Fire Control System

Only fire control systems that can deliver accurate and timely fire alarms that identify the specific location of the fire can be considered effective. Enhanced fire safety can be included in a smart building through the usage of app-based, cloud-based, and wirelessly connected system components. When integrated into a smart building, it is feasible to massively improve fire safety in a variety of ways, ranging from temperature sensors that can determine smoke alarms that can automatically activate in response to an emergency. In addition, fire protection and alarm systems have developed into highly advanced computer-based systems, which combine fire detection and disaster communication systems as an integral component of the entire operations (Acakpovi *et al*., 2021) [2].

vii. Heating, Ventilation, and Air Conditioning (HVAC)

Intelligent heating, ventilation, and air conditioning make use of sensors that are integrated into the building automation system. These sensors compile information about the environment. HVAC equipment gives users the flexibility to fine-tune the heat, humidity, and airflow in several different zones. Early defect prediction and identification in heating, ventilation, and air conditioning (HVAC) systems have the potential to reduce the damage that can be caused to equipment, hence enhancing the dependability and safety of smart buildings (Mesa-Jiménez *et al*., 2021) [26].

viii. Security

The development of so-called smart buildings has given rise to significant issues, including safety and the selection of an alarm verification service in order to be in compliance with regulations and produce an atmosphere that is significantly more comfortable, productive, and safe. The application of technology is required for the creation of user-centric smart buildings by organizations. These buildings must be able to keep people safe from physical threats, allow for a safe return to the workplace following a pandemic, and continue to operate normally in the event of Internet interruptions such as cyber-attacks (S. F. A. Shah *et al*., 2022) [33].

ix. Weather System

The term temperature refers to a physical quantity that indicates the relative levels of heat and cold; in the context of building control, it is a very important parameter. The ability of modern buildings to make temperature adjustments automatically has the potential to both make people's living and working environments more comfortable and save a significant amount of energy. The most typical being the wind that is cold in the summer and the wind that is warm in the winter. The primary purpose of the wind sensor is to determine the velocity of the wind within the ventilation ducts while also performing volumetric calculations on the air passing through it (S. F. A. Shah *et al*., 2022) [33].

Table 1: Machine learning algorithms, the objective of IoT technologies, and their domain in smart building applications.

S/N	Machine Learning Models/Algorithms	Objectives in IoT Technologies	Smart Buildings Applications Domain	Advantages	Disadvantages
1	ANNs	Forecasting and Modeling.	Reduce energy usage based on intelligent sensors.	Excellent accuracy and comfortable monitoring	Complex
2	WNN	Forecasting events based on time series data.	Used in building lighting and shading systems.	Excellent consistency	Low speed
3	Deep learning	It is helpful in both the prediction of data and the modeling of patterns.	Useful for designing and modeling energy- efficient systems.	High precision and acceptable speed	Very complicated
4	Time Series Analysis	High dimensionality	Generates reliable prediction results for building energy.	Predict the Future	The observations are not independent of one another
5	Regression	Behaviour prediction.	Discover the environmental and physical variables that contribute to smart building energy efficiency.	Rapid speed	Unreliable precision
6	Deep Reinforcement Learning	Systematic decision-making.	It has the potential to address the difficulties of energy efficiency in smart buildings.	Solve complicated tasks	Very complicated
7	Decision Tree Classification	Maps several decisions.	Predicts the danger of an outage and handles energy management and energy usage in smart buildings.	Simple to understand	Relative inaccurate
8	Genetic Algorithms	Optimization of issues.	Managing loads optimally and enhancing energy efficiency.	Excellent accuracy	Low speed
9	Support vector Machines	The organization of data and the protection of it in IoT.	Prediction of the amount of energy used in buildings.	Excellent accuracy	It is complex and the speed is low

Source: (S. F. A. Shah *et al*., 2022) [33]

Methodology

For the purpose of this study, the researcher reviewed and analysed previous literature which has been published in the field of smart buildings, energy efficiency and IoT technology, in order to collect all representative technologies regarding Heat, Ventilation, Air Condition systems (HVAC), Renewable Energy systems (RES), Building Energy Management Systems (BEMS) and generally energy efficient methods applicable to smart buildings. The journals were gathered from major journal outlets such as google scholar and science direct which has a wide range of journals within the subject of this study and of high validity.

Results

A smart building is one that uses information to improve user comfort and building function through the use of automated control systems and other features (Dong *et al*., 2019) [9]. The integration of artificial intelligence (AI) with IoT devices and buildings has the potential to enhance the resident experience, increase operational efficiency, and optimize the use of available space and assets (Farzaneh *et al*., 2021) [11]. Building systems may now independently integrate surplus data from IoT devices and tenant behaviour to improve environmental effectiveness, streamline workflows, and provide new insights thanks to artificial intelligence. The learning capabilities of IoT and AI platforms enable the development of creative new services for communication with building occupants (Jia *et al*., 2019) [17]. These technologies have the ability to save expenses by means of automated operation processes. AI technology can be used in smart buildings to improve automation, control, and consistency, thus reducing energy use. In smart buildings, many machine learning techniques are compared and used. Artificial intelligence (AI) techniques are being used in building energy systems. Examples of energy equipment found in smart buildings include diesel generators (DGs), wind turbines (WTs), photovoltaic panels (PVs), thermal energy storage systems, electric energy storage systems, lighting systems, HVAC systems, window management systems, blind systems, electric vehicles (EVs), electric heaters (EWHs), gas boilers, and washing machines (WMs) (S. F. A. Shah *et al*., 2022; L. Yu *et al*., 2021) [38]. Because these pieces of equipment have such a large impact on the environment, society, and economy, it is imperative that their scheduling be done with coordination.

Conclusion

Smart buildings seek to maximize industry 4.0 which makes it more efficient and environmentally sustainable. Recent developments as referred in this study identifies the integration of IoT in the building sector as a contributor to improving energy efficiency and consumption in smart buildings. There are many advantages to using IoT technology in smart buildings, but there are drawbacks as well. An introduction to Internet of Things technology and its application to smart buildings has been provided in this review. Also covered are the IoT device platform and its fundamental parts. Smart building Internet of Things (IoT) devices provide a number of difficulties that require solutions. AI-based systems for smart buildings which includes lighting management system, protective schedulers, large amounts of data, fire control system, heating, ventilation, and air conditioning (HVAC), security, and weather system were further discussed.

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