SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I10P106

Volume 10 Issue 10, 54-60, October 2023

Original Article

Enhancing Energy Efficiency in Mogadishu: IoT-Based Buildings Energy Management System

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Received: 06 August 2023 Revised: 09 September 2023 Accepted: 07 October 2023 Published: 31 October 2023

Abstract *- Energy is a fundamental necessity for human life and the cornerstone of modern industrial economies. In our increasingly connected world, the Internet of Things (IoT) has emerged as a transformative force across various sectors, including energy management. This paper explores the deployment and impact of the Energy wastage controlling and monitoring system, an IoT-based solution, in modern buildings in Mogadishu, Somalia, where energy efficiency is critical due to limited energy resources and high costs. The research reveals the system's capacity to significantly reduce energy consumption by strategically employing motion detection sensors to automate lighting, heating, and cooling based on occupancy and environmental data. Additionally, integrating temperature and humidity sensors contributes to maintaining optimal indoor conditions, enhancing occupant comfort, and curbing unnecessary energy use. A dedicated mobile application empowers users with real-time access to sensor data and remote control over connected devices, promoting active engagement in energy-saving practices. The system effectively addresses phantom power consumption by powering down electrical sockets during non-working hours, resulting in substantial energy savings. Beyond environmental benefits, reduced energy consumption translates into tangible cost savings for building owners and occupants, making buildings more economically viable and attractive. The system's modular design allows for scalability and adaptability to various building types and sizes, fostering tailored energy-efficient solutions. Despite initial setup costs and maintenance challenges, the Energy Wastage Controlling and Monitoring System signifies a significant stride toward achieving energy efficiency in Mogadishu and similar urban environments. It offers an intelligent and automated approach to energy management, contributing to sustainability, cost savings, and occupant comfort. Furthermore, this research underscores the broader implications of IoT-based energy management, emphasizing its potential to address energy challenges in emerging urban centres worldwide. As ongoing research and development efforts persist, IoT technology is poised to shape the future of smart buildings and promote sustainable energy practices, heralding a more efficient and environmentally conscious end.*

Keywords *- Energy, Electricity consumption, Modern buildings, Internet of Things, Sensors.*

1. Introduction

Energy is essential to human life and crucial for various activities. Energy provides services for cooking, space and water heating, lighting, health, food production and storage, education, mineral extraction, industrial production, and transportation [1]

Energy is the foundation of the modern industrial economy, drives economies, and sustains societies [2]. Energy consumption is closely linked to the quality of life, as evidenced by studies that have explored the relationship between electricity consumption and human development [3].

Overall, energy, particularly electricity, is crucial for meeting human needs, enhancing quality of life, and promoting sustainable practices [4]. The IoT technology has revolutionized various sectors, including energy management. By integrating IoT devices and sensors into buildings, we can collect real-time data on energy consumption, identify areas of wastage, and optimize energy usage [5, 6].

In today's modern world, energy wastage is a pressing issue that must be addressed to promote sustainability and reduce costs [7].

Despite lacking a national power grid, Somalia heavily relies on imported fuel, wood, and charcoal to meet its energy needs. This reliance on traditional energy sources contributes to environmental challenges and high energy costs for the population [8].

Additionally, the lack of efficient energy management systems in buildings further exacerbates the problem of energy wastage [9]. Somalia's energy management systems are often outdated and inefficient, leading to unnecessary energy consumption and increased costs.

Without proper monitoring and control mechanisms, buildings in Somalia are prone to energy wastage due to inefficient appliances, improper lighting and heating/cooling systems, and lack of awareness about energy-saving practices [10].

IoT technology can improve energy efficiency in modern buildings in developing countries by implementing intelligent control systems. IoT systems and technologies can be expanded to increase energy efficiencies in residential and commercial buildings by integrating sensors, actuators, and control strategies for collecting information, activating appliances, and monitoring data to forecast energy consumption [11].

Retrofitting existing buildings with IoT sensor networks provides a cost-effective solution for efficient energy management, allowing for automation and optimization of energy usage [12]. Additionally, education on using IoT technology for energy audit and management can increase awareness and encourage energy-saving behaviours in the community [13].

This is particularly challenging for buildings in Somalia, where efficient energy usage is crucial. To tackle this problem, an IoT-based energy wastage monitoring system can be implemented. The use of IoT technology in Somalia is becoming increasingly popular due to its ability to optimize the technology infrastructure of Somalia [14].

Previously, several IoT-based monitoring systems were implemented in Somalia. An IoT-based agricultural irrigation system powered by renewable energy sources (solar power) monitors and improves growth while minimizing resource loss.

Moreover, an IoT-based agricultural draught system was designed to identify draughts early to mitigate the effects of draughts in Somalia. Another IoT-based study on flood detection monitoring systems was developed in Somalia to minimize floods' impacts. Also, IoT water quality monitoring examines its potential to enhance the sustainability of our water resources and quality and foster effective decision-making processes for water management and conservation.

To our knowledge, Somalia has no Internet of Things-based system to reduce energy wastage. In this study, we propose and build an Internet of Things-based energy management to address efficient electricity management in modern buildings to reduce electricity consumption. Specifically, we will delve into IoT-based energy wastage monitoring for contemporary buildings in Somalia. We aim to examine the advantages of implementing such a system, anticipate potential challenges, and propose viable solutions. By gaining insights into the potential of IoT technology in energy management, we can lay the foundation for a more sustainable future in Somalia and beyond its borders.

2. Related Work

Electricity consumption monitoring systems have become essential to ensure efficient electrical energy usage and prevent wastage. These systems utilize various technologies such as sensors, relays, and internet connectivity to monitor and control power consumption [15]. Researchers around the world have proposed several studies to reduce energy wastage.

Luechaphonthara and Vijayalakshmi propose developing an IoT-based application for monitoring electricity power consumption in home appliances. The system uses a low-cost electricity monitoring device with a Wi-Fi module to collect data from appliance sensors. It sends it to a cloud server for storage and monitoring. The analysis of electricity consumption data collected from a refrigerator and water dispenser in a household shows that consumption is higher on weekends and at night.

The study concludes that smart systems can help consumers monitor and adjust their electricity usage to reduce costs [16]. Adkhar and Afianti propose a power consumption monitoring system that utilizes telegrams and LCDs to prevent overconsumption and protect electronic devices. The design incorporates a digital multi-meter and the PZEM-004T sensor for accurately measuring power usage.

The results demonstrate the suitability of the PZEM-004T sensor for measuring voltage and electric current. Additionally, the system includes automatic control through relays to disconnect power when the desired capacity is exceeded. The monitoring results can be accessed remotely through the Telegram application. The paper also provides detailed instructions for connecting the Telegram application to a microcontroller MCU node for remote control functionality [17].

Indikawati and Zamroni propose a forecasting system for household electricity consumption using IoT smart home data. The system utilizes the Extreme Gradient Boosting algorithm and time-series data from a smart meter dataset. The authors evaluate the importance of different time-series features and resample the dataset. The experimental results show that the forecasting system works well with small datasets using one-hour downsampling. The system uses the

XGBoost library for training the dataset and the scikit-learn library for statistical computation. The results demonstrate that the system can make accurate predictions of household electricity consumption with a small amount of training data. The best results were obtained when resampling the data over 1 hour [18].

In their research paper, Uden dhran et al. proposes using machine learning and IoT to optimize energy consumption in commercial buildings. The authors investigate the potential of using Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) in smart energy consumption control systems. They aim to analyze the impact of these algorithms on energy consumption patterns and evaluate their efficiency and effectiveness in reducing energy consumption and costs while maintaining comfort for occupants.

The study compares the performance of ANN and SVM-based algorithms regarding energy consumption reduction and cost savings. The study results provide insights into applying these smart energy consumption control systems in commercial buildings and contribute to developing more sustainable and energy-efficient buildings [19].

However, despite this field's growing body of research, several research gaps must be addressed. Existing studies have explored various aspects, such as IoT-based applications for home appliances, power consumption monitoring with sensors and relays, forecasting systems for household electricity consumption, and machine learning and IoT use in commercial buildings.

Nevertheless, these studies often focus on isolated aspects of electricity consumption monitoring, lacking holistic approaches that integrate these technologies and methodologies. One significant oversight in the current literature is the lack of attention to phantom electricity, which refers to the energy consumed by appliances and devices in standby mode. This oversight is a crucial research gap because it can account for a substantial portion of a household's electricity usage.

Therefore, a notable research gap exists in developing comprehensive electricity consumption monitoring systems that consider efficient appliance operation and simultaneously address the issue of phantom electricity. These systems should be designed to maintain the comfort and convenience of human users while actively reducing overall electricity consumption by eliminating wastages, particularly in standby power. Integrating human needs and preferences to minimize wasteful electricity consumption is crucial for more sustainable and cost-effective energy management solutions. Such an approach would bridge the current gaps in the field and contribute to developing more efficient and user-friendly electricity consumption monitoring systems.

3. Method

This research aims to develop an Internet of Things (IoT) based energy management system for modern buildings in Mogadishu, Somalia. The method comprises an Arduino Uno microcontroller as its central component, motion detection sensors for occupancy monitoring, and temperature and humidity sensors for environmental control. Additionally, the system features an automation component to power down lights, air conditioning, and electricity outlets after regular working hours to minimize energy wastage.

The Arduino Uno microcontroller was chosen due to its adaptability and compatibility with various sensors and actuators. Motion detection sensors will be strategically positioned in each room to detect human presence. In contrast, temperature and humidity sensors will maintain optimal comfort levels while minimizing energy consumption. A control logic was programmed into the Arduino Uno microcontroller through a relay module to implement the desired functionality. This logic incorporated algorithms that determined when to activate or deactivate lights and air conditioning based on occupancy and environmental conditions.

The primary goal is to optimize energy consumption while ensuring occupant comfort. One essential feature of the system is its post-working hours automation. After regular working hours, the system autonomously powers off all lights, air conditioning units, and electricity outlets. This step aims to prevent electricity wastage during non-peak hours, contributing significantly to sustainable energy management. Data collection and analysis were integral components of the research.

The system continuously collects data from the motion sensors, temperature and humidity sensors, and energy usage within the building. The collected data undergoes rigorous analysis to enhance the system's overall performance. These analyses were crucial in interpreting the data and deriving meaningful insights. The below Figure 1 shows the proposed system architecture.

A series of testing scenarios were designed and will be executed to evaluate the system's efficacy. These scenarios encompassed various occupancy patterns, environmental conditions, and energy demands to assess the system's adaptability and responsiveness. Validation of the system's performance involved comparing energy consumption and comfort levels with and without the IoT-based energy management system. This validation process aims to demonstrate the system's capability to reduce electricity consumption while maintaining occupant comfort.

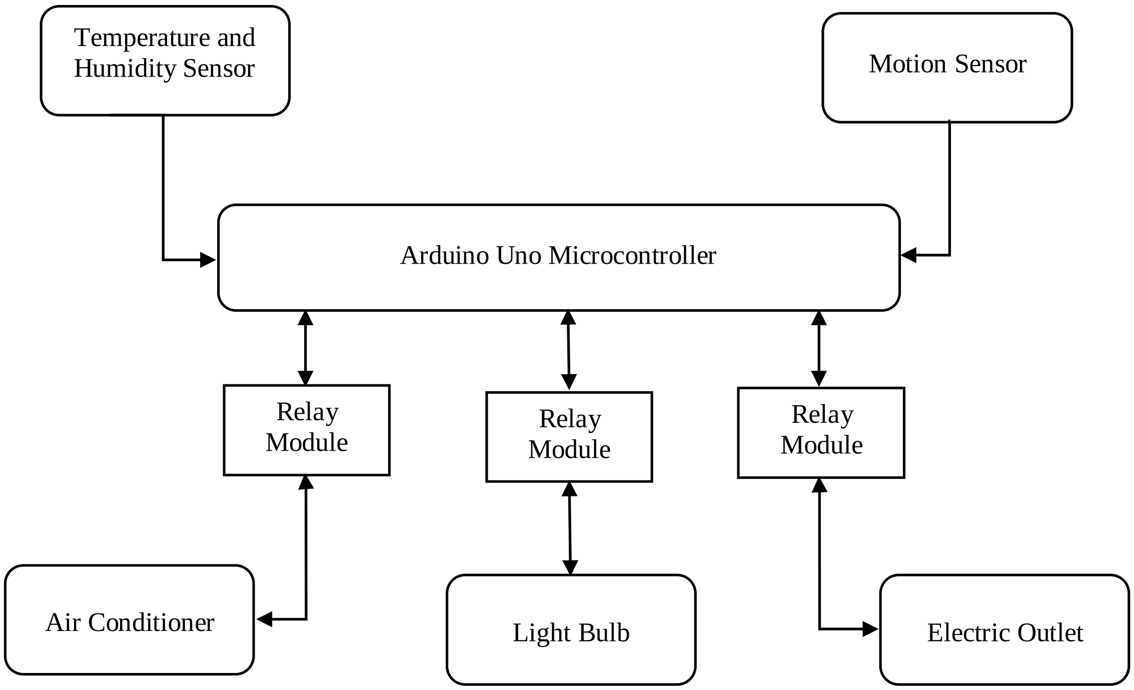

Fig. 1 Proposed system architecture

3.1. Hardware Component

The system's hardware includes the Arduino Uno, temperature and humidity sensor, motion detection sensor, and relay module. The following sections will briefly introduce these components and discuss their respective functionalities.

3.1.1. Arduino Uno

Arduino Uno is a microcontroller board that is widely used in various projects. It is essential for projects because it provides a platform for controlling and interacting with different electronic components [20]. The Arduino Uno microcontroller acts as the central control unit of the system. It receives the data streams from the deployed sensors and processes this information to make informed decisions.

3.1.2. Motion Detection Sensor

Motion Detection sensor is a device that can detect and determine a user's or object's motion. It typically includes an accelerometer to measure gravitational acceleration readings and an angular acceleration sensor to measure angular acceleration readings [21]. The motion detection sensor's input determines whether specific areas are occupied or vacant. Based on this input, the microcontroller triggers actions accordingly. For instance, it activates or deactivates the light bulbs in response to detected occupancy, reducing unnecessary energy consumption.

3.1.3. Temperature and Humidity Sensor

A temperature and humidity sensor is a device used to measure both temperature and humidity levels in a given environment. It is designed to provide accurate and precise readings for these two parameters [22]. Temperature and humidity sensor data guide the control of air conditioning units, ensuring that cooling or heating is only engaged when required, thereby optimizing energy use.

3.1.4. Relay Module

A relay module is an external electronic device that interfaces with an Arduino Uno microcontroller to control high-power electrical devices or circuits. It serves as an interface between the low-voltage, low-current signals from the Arduino and the higher-voltage and higher-current loads you want to control, such as lights, motors, heaters, or appliances.

A relay module is connected to a power sensor to control and monitor electricity consumption, stopping using electric loads if power consumption exceeds a predetermined capacity [23]. The relay module is used in this project to turn on/off the lights, air conditioning, and electrical outlets based on the commands from the Arduino Uno microcontroller.

4. Results and Discussions

The deployment of the energy wastage controlling and monitoring system using IoT in modern buildings in Mogadishu, Somalia, produced substantial improvements in energy efficiency and waste reduction. A pivotal finding from the research is the system's ability to significantly reduce energy consumption through strategically placing motion detection sensors throughout the building. These sensors automatically switched off lights in unoccupied rooms, resulting in marked electricity savings. Furthermore, integrating temperature and humidity sensors was crucial in maintaining optimal environmental conditions within the building. This boosted occupant comfort and curtailed unnecessary heating and cooling operations, leading to a substantial decrease in energy usage for climate control.

The dedicated mobile application emerged as a powerful tool, granting users real-time access to sensor data and remote control over connected devices. Users expressed high satisfaction with the application's convenience and user-friendliness, empowering them to engage in energy-saving practices actively. The below Figure 2 shows the mobile application interface of the system.

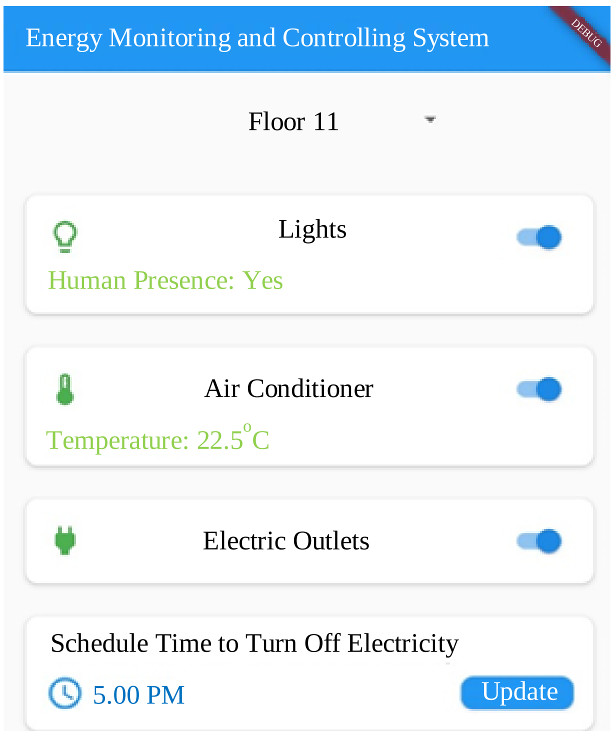

Fig. 2 Mobile application interface of the system

The system also effectively tackled phantom power consumption during non-working hours by powering down electrical sockets. This feature significantly contributed to overall energy savings, mainly when the building was vacant. The real-time monitoring capabilities further enabled users to track energy consumption patterns, facilitating informed decisions about energy management.

This system was tested and validated in a modern building in the Waaberi district of Mogadishu, Somalia. The project yielded substantial reductions in electricity consumption, with an average decrease of over 40%. Tables 1 and 2 below summarize electricity consumption data for the six months before and after the implementation of the system, respectively.

Table 1. Electricity consumption before system implementation

No.	Month	Kwh	Rate per kWh	Amount
1	August 2022	42,713	$ 0.46	$19,647.98
2	September 2022	49,146	$ 0.46	$22,607.16
3	October 2022	41,654	$ 0.46	$19,160.84
4	November 2022	41,210	$ 0.46	$18,956.6
5	December 2022	43,219	$ 0.46	$19,880.74
6	January 2023	46,917	$ 0.46	$21,581.82
Average of the six months				$20,305.86

Table 2. Electricity consumption following system implementation

No.	Month	Kwh	Rate per kWh	Amount
1	February 2023	27,718	$ 0.46	$12,750.28
2	March 2023	25,421	$ 0.46	$11,693.66
3	April 2023	25,821	$ 0.46	$11,877.66
4	May 2023	26,211	$ 0.46	$12,057.06
5	June 2023	24,569	$ 0.46	$11,301.74
6	July 2023	23,824	$ 0.46	$10,959.04
Average of the six months				$11,773.24

The energy wastage controlling and monitoring system signifies a significant stride toward achieving energy efficiency in rapidly evolving urban environments such as Mogadishu, Somalia. The ensuing discussion delves into the broader implications of these research findings.

The system's capacity to intelligently reduce energy consumption by automating lighting, heating, and cooling based on occupancy and environmental data is a noteworthy contribution to sustainability efforts. In regions with scarce and costly energy resources, such as Mogadishu, this becomes even more critical for long-term environmental and economic sustainability.

Furthermore, the user-friendly mobile application empowers building occupants and administrators to participate in energy conservation efforts. By providing control and real-time information, the system enhances convenience and raises user awareness regarding energy management.

Beyond its environmental merits, reducing energy consumption translates into tangible cost savings for building owners and occupants. Lower electricity bills enhance the economic viability of buildings and make them more appealing to prospective tenants. The system's modular design allows for scalability and adaptability to different building types and sizes. This versatility is pivotal for broader adoption in diverse urban settings, enabling the implementation of tailored energy-efficient solutions. Acknowledging challenges associated with initial setup costs and ongoing maintenance is crucial. Subsequent research and development endeavours could focus on cost-effective sensor deployment and further enhancing the system's scalability to address these challenges effectively.

The existing systems focus on monitoring and managing electricity consumption in household appliances, and this system takes a broader approach, aiming to enhance energy efficiency and reduce waste in a commercial building setting. It achieves this by strategically placing motion detection sensors throughout the building, automatically controlling lighting in unoccupied rooms, and integrating temperature and humidity sensors for optimized environmental conditions.

The dedicated mobile application gives users real-time access to sensor data and remote control over connected devices, promoting active engagement in energy-saving practices. Furthermore, this system addresses phantom power consumption by powering down electrical sockets during non-working hours, contributing significantly to overall energy savings, particularly in vacant periods. The system's real-time monitoring capabilities enable users to track energy consumption patterns, facilitating informed decisions about energy management. Implemented and validated in Mogadishu's Waaberi district, your project yielded substantial reductions in electricity consumption, with an average decrease of over 40%. This innovative approach represents a significant advancement in IoT-based energy management for commercial buildings.

Furthermore, the energy wastage controlling and monitoring system, propelled by IoT technology, holds significant potential to augment energy efficiency in modern buildings in Mogadishu, Somalia, as it's the growing city and the capital of Somalia and analogous urban areas. It furnishes an intelligent and automated approach to monitor and regulate energy consumption, ultimately contributing to sustainability, cost savings, and occupant comfort. As ongoing research and development persist in this field, it will play a pivotal role in addressing energy challenges and shaping the future of smart buildings in emerging urban centres.

5. Conclusion

The deployment of the energy wastage controlling and monitoring system using IoT technology in modern buildings in Mogadishu, Somalia, has yielded remarkable results in enhancing energy efficiency and reducing wastage.

This research has demonstrated that strategically placed motion detection sensors, integrated temperature and humidity sensors, and a user-friendly mobile application are all critical components in achieving these improvements. The system's ability to intelligently reduce energy consumption by automating lighting, heating, and cooling based on occupancy and environmental data significantly contributes to sustainability efforts.

In regions like Mogadishu, where energy resources are scarce and costly, such innovations are essential for long-term environmental and economic sustainability. Moreover, the user-friendly mobile application empowers building occupants and administrators to actively participate in energy conservation actively, enhancing convenience and raising awareness about energy management.

Beyond its environmental benefits, reducing energy consumption translates into tangible cost savings for building owners and occupants, enhancing the economic viability of buildings and making them more attractive to potential tenants. The system's modular design and scalability are crucial for broader adoption in diverse urban settings, allowing for tailored energy-efficient solutions.

Acknowledging the challenges associated with initial setup costs and ongoing maintenance is essential. Future research and development efforts should focus on cost-effective sensor deployment and further enhancing scalability to address these challenges effectively.

In summary, the energy wastage controlling and monitoring system, driven by IoT technology, has the potential to significantly enhance energy efficiency in modern buildings in Mogadishu, Somalia, and similar urban areas. It offers an intelligent and automated approach to monitor and regulate energy consumption, contributing to sustainability, cost savings, and occupant comfort. As research and development in this field continue, this system will play a pivotal role in addressing energy challenges and shaping the future of smart buildings in emerging urban centres.

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