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ENERGY CONSUMPTION AND AIRCONDITIONING SYSTEM CONTROL WITH IOT INTEGRATION

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Abstract

The development of an energy consumption and air conditioning system control designed to reduce energy wastage from an Air Conditioning Unit. The primary objective is to monitor and control key parameters such as power consumption, voltage, current, and real-time kW usage, while also tracking classroom occupancy using Passive Infrared (PIR) sensors. Via Automated control, we preferred to easily access the appliance through the internet. Data is transmitted to the Arduino IoT Cloud, allowing real-time monitoring and control via smartphones and laptops. Results show that the system effectively reduces unnecessary energy consumption by automatically adjusting the Air Conditioning Unit's operation based on occupancy and energy data. In conclusion, this smart energy management system demonstrates the potential of IoT technology in promoting energy efficiency, offering a practical solution for sustainable classroom environments. This feature serves as a regulatory checker, enabling end-users to make informed decisions about their energy consumption.

Keywords:

Control, Consumption, Energy, Integrating, Internet of Things (IoT)

1. INTRODUCTION

Uncontrolled appliance use often results in inefficient energy utilization and massive energy waste. In response to this issue, the study aims to develop an automated IoT-based energy management system that utilizes Cloud Interface Controls for remote monitoring and actuation functions. As well as that, the HVAC system is a significant source of greenhouse gas emissions and building energy use, so the study suggests using environmental sensors to automate and dynamically control the system.[1, p. 31–55]. The study aims to create an innovative classroom using an IoT-based ESP32 microcontroller energy management system that can automatically monitor and introduce changes to the HVAC system in real time. The rapid growth in global electricity demand is an undeniable challenge that modern societies must address. The International Energy Agency (2024) projects a 3.4% annual increase in electricity demand through 2026, underscoring the urgent need for effective energy management solutions. Despite advancements in energy production technologies, a wasted proportion of generated electricity. The United States wastes approximately 66.7% of its produced energy alone, indicating inefficient energy utilization [2]. One of the primary culprits of high energy consumption in buildings is HVAC systems, which contribute 38% of a building's energy use and 12% of the total energy consumed [3].

This project aims to create an energy management system that utilizes an IoT-enhanced solution for real-time monitoring. This system can monitor consumption hourly, daily, and weekly, utilizing passive infrared sensors for actuation and temperature/humidity sensors for real-time classroom environmental status monitoring. The system aims to optimize energy usage through intelligent automation and precise monitoring of environmental conditions. By integrating passive infrared sensors, the system ensures that air conditioning units operate only when necessary, reducing energy waste. Additionally, temperature and humidity sensors provide real-time data to maintain an optimal classroom environment, enhancing energy efficiency and comfort.

The rapid advancement of the Internet of Things (IoT) has transformed conventional building management systems into intelligent and interconnected platforms capable of monitoring and controlling electrical devices in real time. By integrating wireless communication, cloud computing, and embedded sensor technologies, IoT enables seamless data acquisition, remote access, and automated decision-making. In educational institutions, where classrooms and laboratories operate for extended hours, IoT-based energy management systems provide an effective approach for minimizing unnecessary electricity consumption while maintaining a comfortable learning environment. These systems support predictive maintenance, enhance operational efficiency, and reduce overall energy costs through continuous monitoring and intelligent control [12].

Heating, Ventilation, and Air Conditioning (HVAC) systems account for a significant portion of electricity consumption in educational buildings. Conventional HVAC operation relies heavily on manual switching or fixed schedules, often resulting in air conditioning units operating even when rooms are unoccupied. Such practices increase electricity expenses, accelerate equipment wear, and contribute to higher greenhouse gas emissions. Integrating occupancy sensors, temperature and humidity sensors, and cloud-based monitoring enables intelligent control strategies that activate HVAC systems only when required, thereby improving energy efficiency without compromising occupant comfort.

The proposed IoT-Enhanced Energy Management System addresses these challenges by combining real-time electrical parameter monitoring, occupancy detection, environmental sensing, and cloud-based remote control into a single integrated platform. Unlike traditional monitoring systems that only record energy consumption, the proposed solution enables both automated and manual control of air conditioning units through the Arduino IoT Cloud using smartphones or laptops. The integration of historical energy data, real-time analytics, and intelligent actuation provides users with actionable insights to optimize energy utilization, reduce operational costs, and support sustainable energy management practices within smart classroom environments.

1.1 SIGNIFICANCE OF THE STUDY

This research will help them discuss and tackle topics related to this research undergraduate project. Furthermore, they can access and control the system by signing in to the Arduino IoT Cloud Server. This research will be a valuable reference for future researchers who plan to do any related study, specifically the undergraduate thesis projects underlying the Bachelor of Science in Electrical Engineering (BSEE). This study helps the university eliminate wasted energy by developing an IoT-Enhanced Energy Management System with real-time monitoring. The findings will benefit the institution and contribute to the growing knowledge about the engineering field.

1.2 STATEMENT OF THE PROBLEM

Current energy management systems in educational settings are insufficient due to their lack of real-time monitoring capabilities and the use of automation and controls, resulting in inefficient energy consumption and increased operational expenses. These systems do not utilize cloud technology to provide remote access to data through mobile applications, which is essential for timely and effective energy management decisions. Furthermore, existing systems do not offer a historical record of power consumption nor support the remote control of appliances. That creates a significant functionality gap, as users cannot monitor their daily consumption or manage appliances effectively.

Additionally, the automation of HVAC systems based on real-time environmental data is lacking. There is a research gap in these devices that are not combined. Currently, systems do not have occupancy, temperature, and humidity sensors built in to make the best use of HVAC systems while keeping an eye on real-time power use to make innovative automated or manual actions. This study means energy efficiency and classroom comfort are not as good as possible. This study looked at how to fix those problems with an IoT-enabled innovative classroom energy management system that includes real-time monitoring, historical data logging, remote control of appliances, and automated management of the HVAC system.

1.3 OBJECTIVES OF THE STUDY

1.3.1 General Objective

This research aims to create a real-time monitoring system for users and smart classroom sensors, utilizing the cloud system to enhance and provide remote access to the data through a mobile application.

1.3.2 Specific Objective

- The goal is to develop a real-time monitor that will serve as a regulatory checker for end users to monitor their hourly, daily, and weekly consumption, both with and without a system.
- We use temperature and humidity sensors inside the classroom to provide real-time data for the classroom's environmental status.
- Automated Airconditioning Controls via IoT Cloud Application

2. REVIEW OF RELATED LITERATURE

Present an IoT-based real-time energy monitoring system that uses Raspberry Pi technology. The technology improved energy management by providing real-time power generation and consumption insights. Key components include a mobile application for user engagement and various sensors for precise data collection. The sensors measure numerous factors, and the Raspberry Pi processes the data to provide real-time monitoring and analysis. The system also has a web interface for remote monitoring, which allows users to access data from anywhere. The study demonstrates the efficacy of this technique in optimizing energy use and fostering efficient energy management practices [4].

They propose Homergy, a system for managing smart home energy based on the Internet of Things, to meet the world's rising energy demand. The solution aims to enhance energy efficiency, particularly in regions where most appliances lack IoT connectivity. Homergy features the Homergy Box, an internet-connected IoT gadget with a built-in microcontroller and opto-coupled relays. It also includes a NoSQL cloud database with streaming capabilities and a secure cross-platform Homergy Mobile App application. The results showed significant energy savings, showing the system's effectiveness [5].

In [6] presented a Smart Home Energy Management System based on IoT technologies to improve residential energy efficiency. The proposed architecture integrated IoT-enabled devices, cloud communication, and mobile applications for remote appliance control and monitoring. The system effectively reduced unnecessary energy consumption by allowing users to manage electrical appliances remotely through smartphones. However, the proposed framework relies heavily on manual user intervention and does not provide intelligent occupancy-based automation or environmental condition monitoring. In addition, the study is limited to residential smart homes and does not address the energy management requirements of educational buildings with dynamic occupancy patterns.

The paper [7] conducted a comprehensive study on campus energy monitoring systems and highlighted the importance of IoT technologies in improving energy management across educational institutions. The study discussed wireless sensor networks, cloud computing, and intelligent monitoring architectures capable of collecting real-time energy data from multiple buildings. The authors emphasized the role of IoT in supporting sustainable campus operations and reducing operational costs. Despite providing an overview of campus-wide monitoring, the study does not propose an intelligent automation framework for HVAC systems. The absence of occupancy detection, environmental sensing, and cloud-based appliance control limits the practical implementation of automated classroom energy optimization.

The authors of [8] proposed an IoT-Based Energy Management System for Smart Classrooms that integrates IoT devices to monitor classroom energy consumption and improve operational efficiency. The system enables real-time monitoring of electrical loads and supports remote access through IoT communication technologies. The authors demonstrated that IoT-based monitoring contributes to better energy awareness and efficient classroom management. However, the proposed system primarily emphasizes monitoring functionality without incorporating intelligent decision-making algorithms for HVAC automation. It also lacks integrated occupancy detection, temperature-humidity sensing, historical energy analytics, and adaptive control strategies for reducing unnecessary energy consumption.

The paper [9] introduced a Smart Classroom Electricity-Saving System integrated with IoT technologies to reduce electricity wastage in educational environments. The system automatically controlled classroom electrical appliances using sensor-based information and cloud connectivity. Experimental evaluation demonstrated noticeable improvements in energy savings compared with manual operation. Nevertheless, the proposed work mainly focuses on general electrical appliance management and provides limited analysis of HVAC energy optimization. Furthermore, the study does not include detailed electrical parameter monitoring such as voltage, current, power, and energy consumption, reducing its capability for comprehensive energy management.

In [10] investigated energy consumption forecasting using various machine learning algorithms to predict future electricity demand in the Philippines. The study evaluated forecasting performance using Mean Absolute Percentage Error (MAPE) and demonstrated that machine learning techniques provide reliable predictions for future energy planning. The research contributes significantly to long-term energy demand forecasting and resource optimization. However, the work focuses solely on prediction models and does not include real-time IoT-based data acquisition, cloud-enabled monitoring, or intelligent control of electrical appliances. Consequently, the proposed forecasting models cannot directly support automated energy-saving actions in smart classroom environments.

The paper [11] proposed a hybrid YDSE–THDCNN-based multi-objective optimization framework for renewable energy management integrated with electric vehicles. The proposed model optimized energy scheduling using deep learning and hybrid optimization techniques to improve renewable energy utilization while minimizing operational costs. The experimental results demonstrated improved optimization performance, system stability, and energy efficiency. Despite its advanced optimization capabilities, the framework targets renewable energy and electric vehicle integration rather than building energy management. It does not incorporate IoT-enabled environmental monitoring, occupancy-aware HVAC automation, cloud-based remote control, or real-time classroom energy monitoring, thereby limiting its applicability to smart educational infrastructures.

Although previous studies have demonstrated the effectiveness of IoT-based energy monitoring and smart home automation, several limitations remain unresolved. Most existing systems primarily focus on monitoring energy consumption without integrating real-time occupancy detection, environmental sensing, and intelligent HVAC control into a unified framework. Many solutions are designed for residential environments and lack adaptability for classroom or institutional applications where occupancy patterns are highly dynamic. Several studies provide cloud-based monitoring but do not support automatic decision-making based on occupancy, temperature, and humidity conditions. In addition, historical energy analysis is often limited, reducing the ability to evaluate long-term energy usage trends and optimize operational efficiency. Existing approaches also lack comprehensive remote-control features that enable users to manually override automated operations through cloud platforms. Furthermore, interoperability between sensing, monitoring, and actuation modules remains inadequate, resulting in fragmented system architectures. These research gaps highlight the need for an integrated IoT-enabled energy management system capable of real-time monitoring, automated HVAC control, cloud-based remote access, historical data logging, and intelligent energy optimization to improve both energy efficiency and occupant comfort in smart classroom environments.

The reviewed literature demonstrates significant progress in IoT-enabled energy monitoring, smart home automation, campus energy management, and machine learning-based energy forecasting. However, most existing studies focus on either monitoring, forecasting, or residential automation independently. Very few systems integrate real-time electrical parameter monitoring, occupancy detection, temperature and humidity sensing, cloud-based remote monitoring, historical energy analytics, and automated HVAC control into a unified platform specifically designed for smart classrooms. To address these limitations, the proposed study develops an IoT-Enhanced Smart Classroom Energy Management System using an ESP32 microcontroller, Arduino IoT Cloud, PIR occupancy sensing, environmental monitoring, and intelligent relay-based HVAC control, providing a comprehensive solution for energy-efficient and sustainable classroom environments.

3. METHODOLOGY

The study's design will introduce the user to the IoT-Enhanced Energy Management System, which focuses on monitoring electricity usage and controlling the air conditioning unit of a laboratory room and integrates with an intelligent controller. Smart outlets are essential for an IoT-Enhanced Energy Management System, offering improved control, monitoring, and automation capabilities.

The Gateway/Hub sends data to the Arduino IoT Cloud Platform for storage and processing. Arduino Cloud will be the central brain or controller for our system. The user interface displays real-time data and provides control options for users. The system also features automated controls for manuals, enabling users to make adjustments via the interface. Integrating these components with specific electrical values allows the creation of a robust IoT-based energy management system that provides comprehensive electrical measurements, real-time monitoring, and user-friendly control mechanisms.

The proposed IoT-Enhanced Energy Management System is designed to provide intelligent monitoring and automated control of classroom energy consumption through the integration of embedded sensors, wireless communication, cloud computing, and intelligent control logic. The overall methodology consists of five major phases: data acquisition, data transmission, cloud processing, decision-making, and appliance control.

Initially, multiple sensors are deployed to collect real-time information from the classroom environment. A voltage and current sensor continuously measures electrical parameters such as voltage, current, power, energy consumption (kWh), and instantaneous power demand. Simultaneously, a Passive Infrared (PIR) sensor detects human occupancy within the classroom, while a temperature and humidity sensor monitors the indoor environmental conditions. These sensors provide comprehensive information required for intelligent energy management.

The acquired sensor data are processed locally using the ESP32 microcontroller, which acts as the central processing unit of the proposed system. The ESP32 filters and formats the sensor readings before transmitting them to the Arduino IoT Cloud through a Wi-Fi connection using the MQTT communication protocol. The cloud platform stores the received data, performs real-time visualization, and maintains historical records that enable users to analyze hourly, daily, and weekly energy consumption patterns.

Based on predefined threshold values and occupancy status, the proposed system executes an intelligent control algorithm. When classroom occupancy is detected, the system evaluates the measured temperature and humidity to determine whether the air conditioning unit should be activated. If no occupants are detected for a predefined duration, the controller automatically switches OFF the HVAC system to eliminate unnecessary power consumption. Users can also manually override the automated operation through the Arduino IoT Cloud dashboard using smartphones or laptops whenever required.

The proposed methodology further incorporates continuous monitoring and feedback mechanisms. Every control action is immediately reflected in the cloud interface, allowing users to observe real-time energy usage, environmental conditions, and appliance status. Historical energy data are archived for future analysis, enabling administrators to identify consumption trends, estimate operational costs, and formulate effective energy-saving strategies.

The overall workflow improves energy utilization by integrating sensing, communication, cloud computing, automation, and remote control into a unified IoT framework. Compared with conventional energy management systems that primarily provide monitoring capabilities, the proposed methodology enables intelligent decision-making, automated HVAC operation, remote accessibility, and comprehensive energy analytics, thereby enhancing energy efficiency, reducing operational costs, and supporting sustainable smart classroom environments.

3.1 INPUT-PROCESS-OUTPUT OF THE SYSTEM

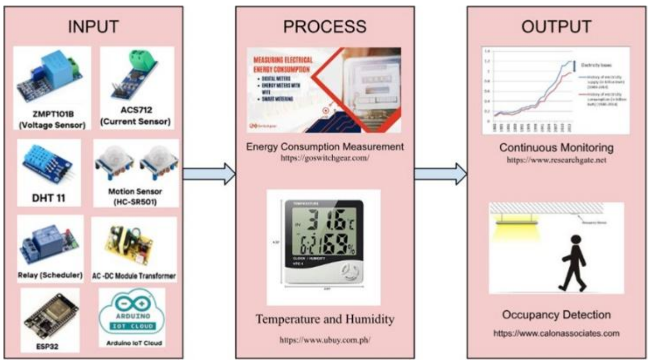

Fig.1. Conceptual Framework of the Study

The Fig.1 illustrates the input (materials), process (use), and output (actual prototype). The first column has a bulleted list of the components required to compile and link it. The second column shows how the components in column 1 work. Finally, the third column contains the output, which is the capstone project.

3.2 PROJECT DESIGN

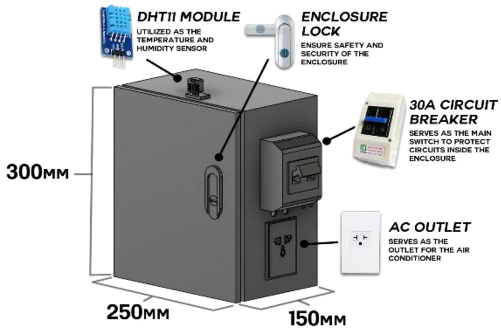

Fig.2. 3D Modelling Design

The Fig.2 illustrates the three-dimensional (3D) model of the proposed IoT-Enhanced Smart Classroom Energy Management System, which integrates sensing, monitoring, protection, and control components within a compact enclosure. The central control box houses the ESP32 microcontroller, relay module, power supply, and associated electronic circuits required for system operation. A DHT temperature and humidity sensor is mounted externally to continuously monitor the classroom's environmental conditions, while a Passive Infrared (PIR) sensor is installed on the front panel to detect human occupancy for automated HVAC control. A Miniature Circuit Breaker (MCB) is incorporated to protect the system against overloads and short circuits, ensuring safe and reliable operation. The enclosure also includes a power outlet that supplies the connected air conditioning unit, enabling automatic switching through the relay module. Additionally, a digital energy meter is connected to measure electrical parameters such as voltage, current, power, and energy consumption, providing accurate real-time monitoring. The integrated design enables seamless communication with the Arduino IoT Cloud, allowing users to remotely monitor system status, energy usage, and environmental conditions while manually or automatically controlling the air conditioning unit. Overall, the 3D model demonstrates a compact, modular, and scalable architecture suitable for deployment in smart classroom environments to improve energy efficiency and reduce unnecessary electricity consumption.

The Fig.3 presents the complete schematic diagram of the proposed IoT-Enhanced Smart Classroom Energy Management System, illustrating the interconnection of sensing, control, power monitoring, and cloud communication modules. The system is built around two ESP32 microcontrollers, where one controller is dedicated to real-time monitoring of electrical and environmental parameters, while the second controller performs appliance actuation and automation. The ACS712 current sensor measures the load current, and the ZMPT101B voltage sensor measures the supply voltage. These measurements are processed by the ESP32 to calculate power and energy consumption in real time. A DHT temperature and humidity sensor continuously monitors classroom environmental conditions, whereas PIR sensors detect room occupancy to enable intelligent HVAC operation. Two servo motors are incorporated for mechanical actuation and prototype demonstration purposes. The monitored data are transmitted wirelessly through the ESP32 to the Arduino IoT Cloud, enabling remote visualization, historical data storage, and manual control via smartphones or laptops. An AC-to-DC power supply module provides the regulated DC voltage required for the electronic components, while a 30 A circuit breaker ensures protection against overloads and short-circuit faults. The system controls the connected 30 A power outlet through a relay module, allowing the air conditioning unit to be switched ON or OFF automatically based on occupancy and environmental conditions or manually through the cloud interface. The integrated architecture enables real-time monitoring, intelligent automation, cloud-based remote access, and reliable protection, thereby improving energy efficiency and reducing unnecessary electricity consumption in smart classroom environments.

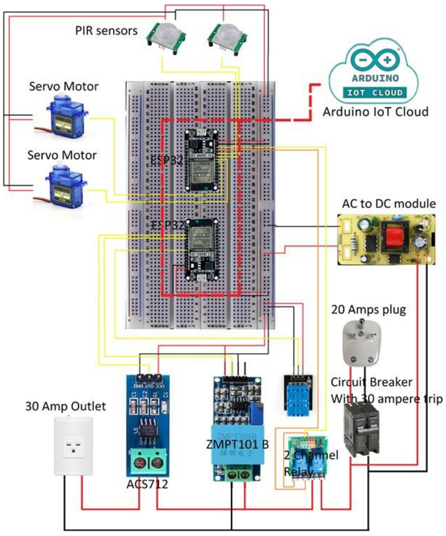

Fig.3. Schematic Diagram of the Study

The Fig.4 illustrates the workflow of the proposed IoT-based Smart Classroom Energy Management System for real-time monitoring and automated control of air conditioning units. The process begins with the initialization of the ESP32 microcontroller and connected sensors, including voltage and current sensors, a temperature and humidity sensor, and a Passive Infrared (PIR) occupancy sensor. The acquired sensor data are transmitted to the Arduino IoT Cloud via a Wi-Fi connection using the MQTT protocol, where the data are stored, analyzed, and displayed through a web-based dashboard accessible from smartphones and laptops. The system continuously monitors electrical parameters, environmental conditions, occupancy status, and HVAC operation. Based on the occupancy information, the controller determines whether the classroom is occupied. If no occupancy is detected, the air conditioner is automatically switched OFF through a relay module to eliminate unnecessary energy consumption. When occupancy is detected, the system evaluates the room temperature against a predefined threshold. If the temperature exceeds the threshold, the air conditioner is turned ON; otherwise, its current operating state is maintained. Every control action is immediately synchronized with the cloud platform, enabling real-time visualization, historical data logging, remote monitoring, manual override, and continuous energy management. This closed-loop control mechanism improves energy efficiency, reduces electricity wastage, and enhances occupant comfort in smart classroom environments.

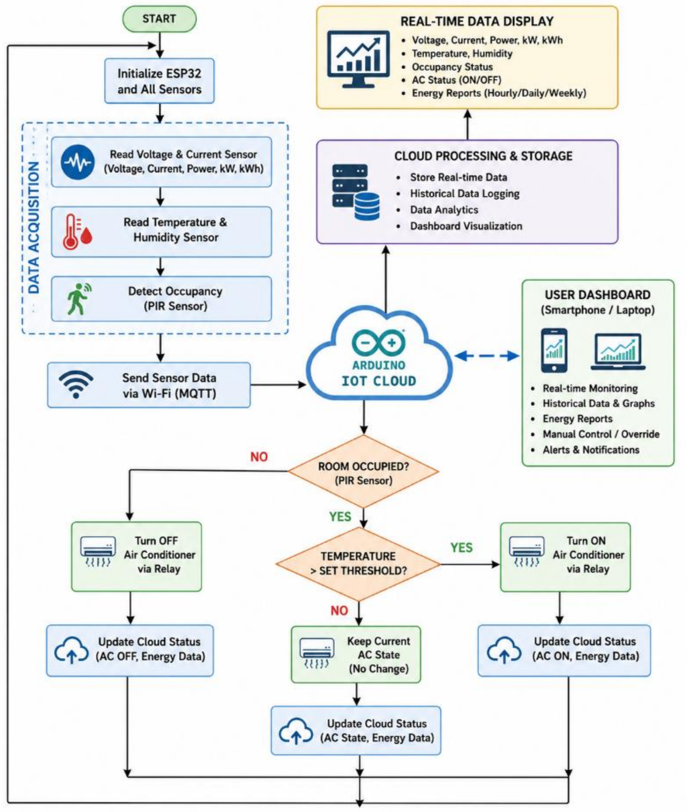

Fig.4. Proposed model

4. RESULTS AND DISCUSSIONS

The proposed IoT-Enhanced Smart Classroom Energy Management System was implemented in a laboratory classroom environment to evaluate its performance under real operating conditions.

The experimental setup consisted of an ESP32 microcontroller integrated with a voltage and current sensor for measuring electrical parameters, a Passive Infrared (PIR) sensor for occupancy detection, a DHT22 temperature and humidity sensor for environmental monitoring, and a relay module for automatic air conditioner control. The ESP32 communicated with the Arduino IoT Cloud through a Wi-Fi network using the MQTT protocol, enabling real-time data acquisition, cloud storage, and remote monitoring via smartphones and laptops.

A conventional digital submeter and a calibrated temperature measuring instrument were used as reference devices to validate the accuracy of the proposed system. Measurements were collected at hourly intervals for eight consecutive hours under normal classroom operating conditions, and the recorded data included voltage, current, power, energy consumption (kWh), temperature, humidity, occupancy status, and HVAC operating state. The system was evaluated in terms of measurement accuracy, communication reliability, automated control response, and cloud-based visualization.

Table.1. Comparison of Instrument Reading and IoT EMS System Temperature

Hour	Instrument Reading (°C)	IoT EMS System Reading (°C)	Difference (°C)
1	30.5	30.0	0.5
2	28.5	28.2	0.3
3	27.0	26.8	0.2
4	25.0	24.8	0.2
5	24.5	24.2	0.3
6	24.0	23.9	0.1
7	23.8	23.7	0.1
8	24.0	23.8	0.2

The Table.1 compares the temperature measurements obtained using the conventional measuring instrument and the proposed IoT Energy Management System (EMS) over an eight-hour observation period. Both measurement methods exhibit a similar decreasing temperature trend, with values reducing from approximately 30°C during the first hour to around 24°C by the eighth hour. The maximum observed deviation between the two methods is approximately 0.5°C, while most readings differ by only 0.1–0.3°C. This close agreement demonstrates that the IoT EMS provides temperature measurements comparable to those of the conventional instrument. The results validate the reliability and accuracy of the proposed IoT-based monitoring system for real-time classroom environmental monitoring. Furthermore, the consistent trend confirms that the integrated temperature sensor can effectively support automated HVAC control, enabling intelligent energy management while maintaining a comfortable indoor environment.

Table.2. Comparison of Conventional Submeter and IoT EMS Energy Consumption

Hour	Conventional Submeter (kWh)	IoT EMS System (kWh)	Difference (kWh)
1	2.42	2.30	0.12
2	2.25	2.20	0.05
3	2.05	2.00	0.05
4	1.98	1.95	0.03
5	1.99	1.97	0.02
6	1.85	1.82	0.03
7	1.84	1.83	0.01
8	1.82	1.81	0.01

The Table.2 presents the comparison between the energy consumption measured using the conventional submeter and the proposed IoT Energy Management System (EMS) over an eight-hour monitoring period. The results indicate that both systems exhibit a similar downward trend in energy consumption, decreasing from approximately 2.4 kWh during the first hour to about 1.8 kWh by the eighth hour. The observed differences between the conventional submeter and the IoT EMS are minimal, ranging from 0.01 to 0.12 kWh, demonstrating a high level of agreement between the two measurement methods. The slight variations can be attributed to sensor calibration tolerance, sampling intervals, and communication latency during data acquisition. Overall, the results confirm that the proposed IoT EMS accurately measures real-time energy consumption while simultaneously providing cloud-based monitoring, historical data logging, and remote accessibility. This validates the suitability of the developed system as a reliable alternative to conventional energy metering for intelligent classroom energy management and HVAC control.

The experimental results demonstrate that the proposed IoT-based Energy Management System accurately monitors classroom energy consumption and environmental conditions while providing intelligent HVAC control. The temperature comparison between the conventional measuring instrument and the IoT EMS showed only minor deviations of less than 0.5°C, indicating high measurement accuracy and reliable environmental monitoring. Similarly, the comparison between the conventional submeter and the IoT EMS energy measurements revealed a maximum variation of approximately 0.12 kWh, confirming the effectiveness of the proposed sensing and data acquisition modules. The PIR sensor successfully detected classroom occupancy and automatically controlled the air conditioning unit according to occupancy status and predefined temperature thresholds, thereby preventing unnecessary energy usage during unoccupied periods. Furthermore, all sensor readings and control actions were synchronized with the Arduino IoT Cloud in real time, allowing users to monitor hourly, daily, and weekly energy consumption remotely through smartphones and laptops. Historical data logging enabled trend analysis and energy usage evaluation, assisting administrators in making informed energy management decisions. Overall, the developed system demonstrated reliable communication, accurate sensing, efficient cloud integration, and intelligent automation, making it an effective solution for improving energy efficiency, reducing electricity wastage, minimizing operational costs, and supporting sustainable smart classroom management.

The performance of the IoT-Enhanced Smart Classroom Energy Management: Real-Time Energy Consumption and Room Status Monitoring. The results will be illustrated as a table and percentage that highlights the precision and accuracy of Energy Management and Actuation to distinguish between various testing and make a prediction according to the given dataset. This also discusses the system's adaptability to the HVAC load conditions and its potential to optimize energy distribution in a real-time system.

5. CONCLUSION AND FUTURE WORK

The proposed IoT-Enhanced Smart Classroom Energy Management System successfully achieved its objective of providing real-time monitoring and intelligent control of classroom energy consumption through the integration of ESP32, environmental sensors, occupancy detection, and the Arduino IoT Cloud platform. The developed system accurately measured electrical parameters, including voltage, current, power, and energy consumption, while simultaneously monitoring classroom temperature, humidity, and occupancy status. Experimental results demonstrated close agreement between the IoT-based measurements and conventional measuring instruments, confirming the accuracy and reliability of the proposed system.

The cloud-based dashboard enabled users to monitor hourly, daily, and weekly energy consumption remotely using smartphones and laptops, while providing historical data for effective energy analysis and decision-making.

Furthermore, the integration of occupancy-based automation and temperature-dependent HVAC control significantly reduced unnecessary energy consumption by ensuring that the air conditioning unit operated only when required. The system combines real-time sensing, wireless communication, cloud computing, and intelligent control into a unified energy management platform that enhances operational efficiency, improves occupant comfort, and reduces electricity costs. Overall, the proposed solution demonstrates the practical applicability of IoT technologies in developing sustainable and energy-efficient smart classrooms. The developed framework can be readily extended to offices, laboratories, commercial buildings, and other educational institutions, serving as a scalable foundation for future smart building energy management systems.

Regarding the results obtained after development and testing procedures, the IoT Enhanced Energy Management System effectively provides hourly, daily, and weekly usage. This feature serves as a regulatory checker, enabling end-users to make informed decisions about their energy consumption. The sensors ensure energy efficiency by determining room occupancy and monitoring environmental conditions. The system offers both manual and automated control modes. Users may control the device using a smartphone or laptop via a manual override button or use sensor-based automated sequences for workless functioning.

We have identified various recommendations that researchers could implement in their future actions. For a more sustainable approach, integrating the system with other sources could allow users to track both traditional and renewable energy consumption. Using voice control like Alexa to make it more reliable in terms of usage. We are developing a large-scale version of this system to support adding heavy or high-rated loads and devices such as electric fans, televisions, refrigerators, and lighting systems. Card tapping or card usage, like RFID, provides access to other schools or family members through integrating a Smart Controlled Remote System for Inverter Type Aircon. Furthermore, the subscription in the cloud server offers up to 25 device connections. Therefore, up to 25 systems can be connected to the same cloud server, allowing better results for industries with multiple HVAC equipment for ACU consumption.

In the future, researchers should improve the system by making it work seamlessly offline with local data storage and control and by making Internet integration more stable so that monitoring and automation can happen all the time. Sealing open-air entrance points and enhancing insulation to manage and maintain the M-419 temperature, resulting in a continuously cool temperature within the room to gain reduced consumption over time. The system is integrated with the room's outlet and lighting systems, with students having limited access, assuring regulated usage and managing energy consumption to keep it low.

REFERENCES

[1] Economic Research Institute for ASEAN and East Asia, "Energy Consumption Survey and Energy Efficiency Indicators", Available at: https://www.eria.org/uploads/media/Research-Project-Report/RPR-202 3-15/09_Chapter-2-Energy-Consumption-Survey-and-Energy-Efficiency-Indicators-..pdf, Accessed in 2023.

[2] International Energy Agency, Available at: https://www.iea.org/reports/electricity-2024/executive-summary, Accessed in 2025.

[3] M. Gonzalez-Torres, L. Perez-Lombard and D. Yan, "A Review on Buildings Energy Information: Trends, End-Uses, Fuels and Drivers", *Energy Reports*, Vol. 8, pp. 626-637, 2022.

[4] B.M. Chandra, A.A.A. Samhan, L. Venkateswarlu and R. Deivanayaki, "Smart Home Energy Management System using Fractional Order PID Controllers with Hybrid Optimization", *Proceedings of International Conference on Recent Innovation in Science Engineering and Technology*, pp. 1-5, 2025.

[5] M.D. Mudaliar and N. Sivakumar, "IoT based Real Time Energy Monitoring System using Raspberry Pi", *Internet of Things*, Vol. 12, pp. 100292-100312, 2020.

[6] E.A. Affum, K. Agyeman-Prempeh, C. Adumatta and J. Dzisi, "Smart Home Energy Management System based on the Internet of Things (IoT)", *International Journal of Advanced Computer Science and Applications*, Vol. 12, No. 2, pp. 1-12, 2021.

[7] M. Deepika, M. Kavitha, N.S.K. Chakravarthy, J. Srinivas Rao and B.M. Chandra, "A Critical Study on Campus Energy Monitoring System and role of IoT", *Proceedings of IEEE International Conference on Smart Electronics and Communication*, pp. 1-4, 2021.

[8] R.J. Begum, M. Parveen and S. Latha, "IoT-Based Energy Management System for Smart Classrooms", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 12, No. 4, pp. 987-995, 2023.

[9] M.W. Nasrudin, N.A. Nordin and W.A. Mustafa, "Smart Classroom for Electricity-Saving with Integrated IoT System", *Journal of Physics. Conference Series*, Vol. 2107, No. 1, pp. 12019-12032, 2021.

[10] E. Torculas, E.J.Q. Rentillo and A.A. Ambita, "Forecasting of Energy Consumption in the Philippines using Machine Learning Algorithms", *Proceedings of IEEE International Conference on Recent Challenges in Intelligent Information and Database Systems*, pp. 424-435, 2023.

[11] C.S. Reddy, B.V. Prasanth, O.P. Suresh and B.M. Chandra, "A Hybrid YDSE-THDCNN Approach based Multi-Objective Optimization of Energy Management for Renewable Energy Sources with Electric Vehicles", *Journal of Energy Storage*, Vol. 45, No. 2, pp. 100-115, 2024.