Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 4, **Number** 2, November 2024
https://doi.org/10.47709/brilliance.v4i2.5082

Smart Light Electricity Automation and Monitoring System Based on the Internet of Things (IOT) on Campus Environment Prototype

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open access

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Article History:
Submitted: 29-11-2024
Accepted: 05-12-2024
Published: 13-12-2024

Keywords:
IoT; Smart Light; Electricity Monitoring; PIR Sensor; LDR Sensor; ESP32; ZMPT101B Sensor; ACS71 Sensor

ABSTRACT

Efficient management of electrical energy is very important in the campus environment to support energy savings. This research aims to design and implement an Internet of Things (IoT)-based Smart Light system that automates light control and monitors electricity consumption in real-time. The system uses an ESP32 microcontroller integrated with PIR sensor and LDR sensor modules for automatic control, as well as ACS712 current and ZMPT101B voltage sensors to monitor electrical power. The collected data is processed in the microcontroller to calculate the electric power and cost, then displayed through a PHP and MySQL-based web dashboard that can be accessed in real-time. Tests were conducted on the campus prototype, showing an average error of 2.78% for current and 0.086% for voltage on indoor devices, and 2.86% for current and 0.343% for voltage on outdoor devices. The system is proven to be able to control lights automatically based on user presence and lighting conditions. Test results show that the system provides accurate monitoring of electricity consumption while improving operational efficiency. For example, the indoor device has higher accuracy in monitoring consumption data than the outdoor device, even though both devices show optimal performance. This system is expected to support electrical energy savings, improve energy use efficiency, and become an innovative solution in IoT-based energy management on campus.

INTRODUCTION

Electrical energy is something that is very important to sustain human life today. Electrical energy is the electrical power used during a certain time (Despa, Nama, & Septiana, 2021). The availability of electrical energy and the growth of power plants are 2 things that must also be considered by every human being. Based on these problems, it is necessary to prevent the occurrence of an electrical energy crisis in the future, one of these efforts is to design electricity savings (Pela & Pramudita, 2021). Lights are a source of lighting to be able to support human visual activities and have an influence on the function of the room.

With the development of science and technology, the state of human civilization has changed for the better. One of them is in the field of technology, this technology is control technology. Current control technology has begun to shift towards automation which requires the use of computers, so that human intervention in control is very small (Galina & Harryanto, 2023).

In general, lighting in the room and outside the campus room (campus corridor) is controlled manually. The problem is that sometimes users forget to turn off the lights when they are not using the room and forget to turn on the outdoor lights when leaving campus. The lights in the room will continue to burn resulting in excessive use of electrical energy and a very high surge in electricity bills and for corridor lights will continue to die resulting in dark access to the campus corridor for students who will leave campus when it gets dark. To save the use of electric power, user awareness is needed to turn off electrical devices that are rarely used in order to save electricity usage (Putra & Mukhaiyar, 2020).

Then the measurement of electrical power carried out so far only uses kWh measuring instruments distributed by PT PLN (Persero). kWh meter is a measuring instrument used to measure the use of electrical energy (Ikhfa & Yuhendri, 2022). The use of these tools cannot provide detailed information regarding how much electricity usage is connected to the kWh meter. Therefore, a tool is needed that can show the use of electric power in real time, making it easier for users to monitor electricity usage (Putra & Mukhaiyar, 2020).

In addition, this research is part of the "Smart Campus" project which includes the integration of several other smart systems such as *Smart Fire Alarm, Smart Garden,* and *Smart Parking.* The goal is to create a more connected and efficient campus environment, where all these systems work synergistically to improve the quality of life and operational efficiency of the campus.

The solution to this problem is to create a Smart Light system using PIR (Passive InfraRed) sensors and LDR Sensor Modules so that this system will work when the surrounding conditions are dark and there are objects approaching the system. Then the ACS712 Current Sensor and ZMPT101B Voltage Sensor will detect the amount and

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voltage current of the electricity that has been used and then processed with an ESP32 microcontroller that has been programmed through the Arduino IDE application. The processed data is then sent to the MySQL database which later using PHP programming, the data that has been stored can be displayed on the *Webserver* according to what you want to display, then the user can access the use of electricity that has been used.

LITERATURE REVIEW

Monitoring and Control System

Monitoring is a systematic process to collect and analyze information based on predetermined indicators and is carried out continuously on an activity, functioning to ensure that the activities carried out are in accordance with the plans that have been made. The results of this process are data that can be used to take corrective or improvement actions for further activities (Hardiyanto., 2018). A control system is controlling one or more quantities in the form of variables or parameters so that they have a certain value. This activity aims to get the best results based on the function of a control system itself (Hidayat, 2017). This control system can be applied in various fields, such as industry, household automation, to information technology, to ensure that the process runs as expected and efficiently. Thus, control systems have a very important role in improving the quality and performance of a system as a whole.

Internet of Things (IoT)

The Internet of Things (IoT) is a technological innovation that has the potential to be one of the major changes in the future. The concept of IoT aims to utilize continuous internet connectivity to integrate physical and virtual objects. By utilizing the ability to capture data and communicate, IoT allows physical objects in the real world to interact with each other through networks and the internet (Sasmito & Wijayanto, 2020).

IoT works on the principle that each device must have an Internet Protocol (IP) address, which serves as a unique identity within the network. This IP address allows the device to receive instructions from other devices within the same network, which are then connected to the *internet* with easy access. This allows users to monitor and control the device remotely via an internet connection. In addition to having an IP address and being connected to the *internet*, each IoT device is equipped with sensors to collect the necessary data. Once the data is collected, the device can process it itself and communicate with other devices that are also connected to the internet and have an IP address. Information is exchanged between these devices, and once the processing is complete, the device can perform the necessary actions on its own or instruct other devices to act. This is the main advantage of IoT technology (Kitchenham, 2004).

Alternating Voltage and Current

AC power can produce voltages and currents with magnitudes and polarities that change cyclically over time. For AC, the electromotive force (EMF) of an AC generator has several arag, which changes as a function of time (Samsugi, Ardiansyah, & Kastutara, 2017). The source of AC electricity comes from an AC generator, known as an alternator. This alternator has a square-shaped coil that rotates in a magnetic field. AC can be divided into alternating current with a sinusoidal profile and non-sinusoidal alternating current. Sine waves are used as a power source for power grids. While non-sinusoidal waves are usually used in inverters.

Electrical Power

Electric power is the amount of electric power measured in watts through the multiplication of two main electrical quantities, namely current and voltage.

1. Real Power
   Real power is the amount of electric power used by pure loads (which are only additive) and produces real power, or power used for actual work energy purposes, this power is what will be converted to turn on electronic equipment in households, the unit for this active power is Watt. Real power (P) can be calculated as follows:
   $$P = V.\ I.\ \mathrm{Cos}\ \varphi \text{...(watts)} \qquad (1)$$
2. Apparent Power
   Apparent power (S) is the amount of electrical power that produces power that does not fully produce effort
   $$S = V.\ I.\ \sin \varphi \qquad (2)$$
3. Reactive Power
   Reactive power is electrical power that does not produce effort and is absorbed by loads that have reactance values, such as containing inductance and capacitance components, or power used for the generation of magnetic flux (magnetic field), the unit is VAR. Reactive power can be calculated by the equation:
   $$Q = V.I.\mathrm{Sin}\ \varphi \text{...VAR} \qquad (3)$$

ESP32

ESP32 is an integrated SoC (System on Chip) microcontroller with 802.11 b/g/n WiFi, Bluetooth version 4.2, and various peripherals. ESP32 is a fairly complete chip, there is a processor, storage and access to GPIO (General Purpose Input Output). ESP32 can be used for a replacement circuit on Arduino, ESP32 has the ability to support

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connecting to WiFi directly (Wagyana & Rahmat, 2019).

PIR Sensor (Passive Infrared)

PIR (Passive InfraRed) sensors are sensors that work using infrared light. Unlike most infrared sensors that consist of IR LEDs and phototransistors, PIRs do not emit light like IR LEDs. True to its name, 'Passive', it only responds to energy from passive infrared rays emitted by the detected object. The object that can be detected by this sensor is usually the human body (Gifson & Slamet., 2009).

Objects that can emit heat are emitting infrared radiation. These objects include living things such as animals and the human body. Human and animal bodies can emit the strongest infrared radiation at a wavelength of 9.4 µm. This emitted infrared radiation is the source of detection for heat detectors that utilize infrared radiation (M & J, 2019).

Figure 1. PIR Sensor

LDR (Light Dependent Resistors) Light Sensor Module

An LDR (Light Dependent Resistor) Light Sensor Module, also known as a photosensitive module or LDR module, is an electronic component used to detect the intensity of light in the surrounding environment. This module utilizes the change in resistance of the LDR based on the level of light it receives.

Figure 2. LDR Light Sensor Module

ACS712 Current Sensor

ACS712 current sensor is a sensor to detect current, ACS712 has a type of variation according to the maximum current of 5A, 20A, 30A. This ACS712 uses 5V VCC. The inbuilt Hall IC captures the magnetic field created by the current flowing via the copper cable inside the sensor, which is then transformed into a proportional voltage. Installing the components inside between the hall transducer and the conductor that generates the magnetic field closely maximizes sensor reading accuracy. The Bi CMOS Hall IC inside, which the manufacturer has designed for great accuracy, will be stabilized by the low proportional voltage.

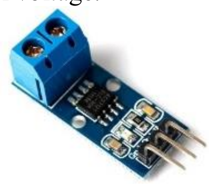

Figure 3. ACS712 Current Sensor

ZMPT101B Voltage Sensor

One of the sensors used to track voltage parameters is the ZMPT101B Voltage Sensor, which has the benefits of an ultra tiny voltage transformer, high accuracy, and reliable power and voltage measurement.

Figure 4. ZMPT101B Voltage Sensor

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PHP

PHP, which stands for *Hypertext Preprocessor* , is a high-level *scripting* language that is installed in HTML documents. The main purpose of using this language is to enable dynamic web design and can work automatically (Hinton, Baliga, Feng, Ayre, & Tucker, 2011). PHP is a *scripting* language that is integrated with HTML and executed on the *server* side. This means that all of its syntax is executed entirely by the *server*, while only the results are sent to the*browser*.

MySQL

MySQL is a database system consisting of one or more tables. As an open-source database server, MySQL has various advantages and is often used in project development. MySQL has an *Application Programming Interface* (API) facility that allows various computer applications written in various programming languages to access MySQL databases (Hinton, Baliga, Feng, Ayre, & Tucker, 2011).

METHOD

The research employed experimental method to design and develop the IoT based Smart Light System focusing primarily on electrical energy consumption automation and monitoring at the campus. The method process involves several phases namely hardware design, software design, system testing and IoT implementation in the system. The details of each of these stages is as follows.

Hardware Design

ESP32 microprocessor is functioning as the data center to receive input from sensor and send data to the server wirelessly. PIR sensor and LDR module are for controlling light automatically whenever motion is detected or makes use of light intensity. The PIR sensor helps in motion detection inside the room while LDR detects the light in the surrounding on corridor. Current Sensor ACS712 and Voltage Sensor ZMPT101B serve to measure current and voltage across the lamp respectively in order to process and determine power usage.

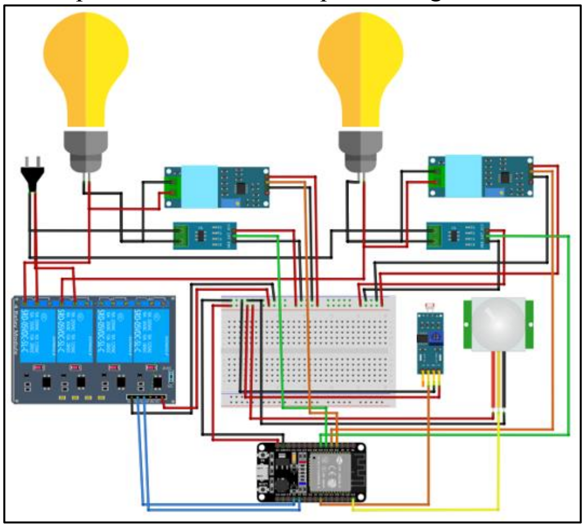

Figure 5. Smart Light System Circuit Design

Software Design

The software part encompasses programming of the ESP32 with the Arduino IDE, web development whereby PHP is used on the backend and MySQL as a database. The electricity consumption data is kept in a database named db_monitoring under the monitoring table. Web dashboard interface is built in a way that allows any user with admin access to monitor the electricity consumption and light control systems in almost real time.

System Testing

System tests were carried out to verify the accuracy of the installed sensors. Voltage sensor ZMPT101B and current sensor ACS712 were tested in different scenarios to evaluate average reading error wattage and voltages in both indoor and outdoor lamp. The system was also tested to ascertain the performance of wireless connectivity and the reliability of the data sent from the ESP32 to the database.

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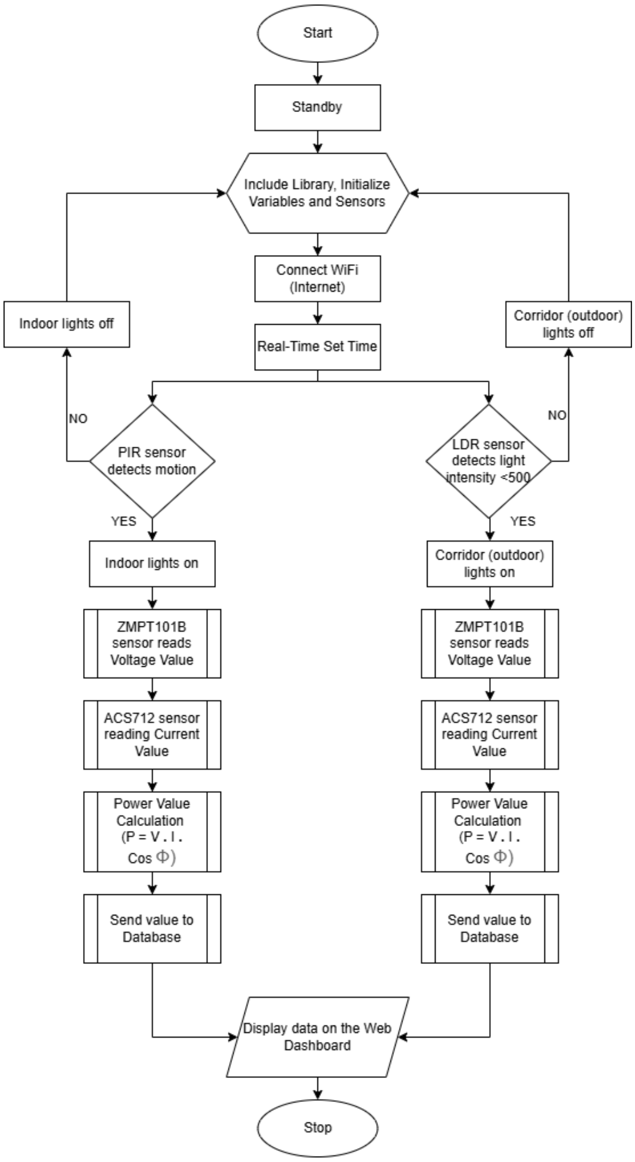

Figure 6. Flowchart of The System Work

Implementation

System employs the HTTP protocol to facilitate communication between the hardware and the server enabling efficient management of electricity consumption data. Data from the microcontroller is periodically sent to the server, hence it can be accessed in real time from the web dashboard.

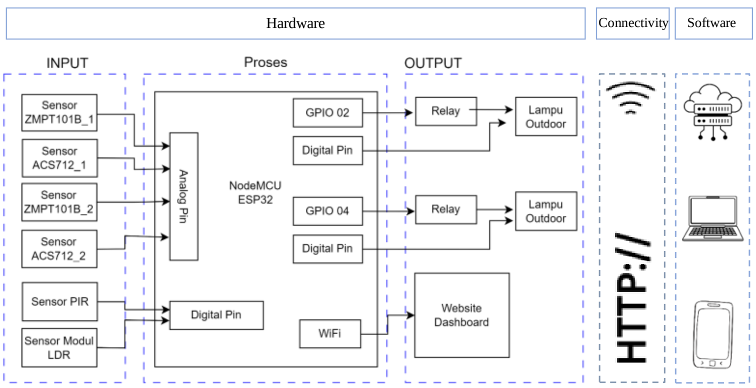

Figure 7. Block Diagram of the Smart Light System

E-ISSN : 2807-9035
Volume 4, **Number** 2, November 2024
https://doi.org/10.47709/brilliance.v4i2.5082

RESULT

ESP32 Connectivity to Wi-Fi

Testing the ESP32's connectivity to a Wi-Fi network is done to ensure the system can send real-time data to the server. The average time required to connect the ESP32 to the network was about 3 seconds, and the connection remained stable throughout the 24-hour test without any significant interruption. The ESP32 connection to Wi-Fi was stable with fast response time and a 0% connection failure rate during the test.

PIR and LDR Sensor Testing

Testing was conducted to measure the accuracy and response speed of the PIR sensor (motion detection) and LDR sensor modules (light intensity detection). The PIR sensor was tested in an active room scenario, while the LDR was tested under changing light conditions.

1. PIR sensor
   The system successfully detected motion within a 60 centimeter radius with a response time of about 0.5 seconds to turn on the lights.
2. LDR Sensor Module
   The LDR detects light intensity with 95% accuracy against the lux meter standard, ensuring the light turns on when the light is less than the specified threshold.

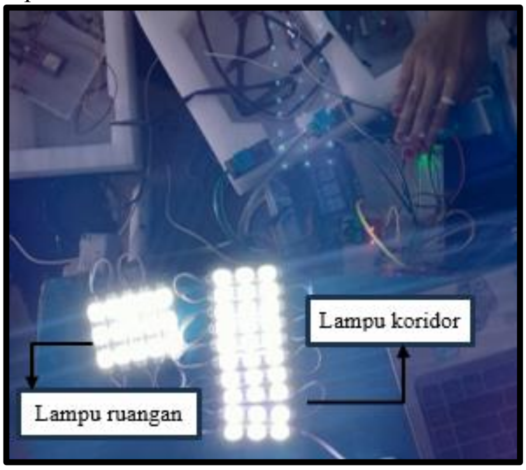

Figure 8. PIR and LDR Sensor Testing

ACS712 Current and ZMPT101B Voltage Sensor Testing

This test aims to determine the accuracy of the ACS712 and ZMPT101B sensors in measuring current and voltage. The following are the average error results found in sensor testing:

Table 1. Testing Accuracy of ZMPT101B Sensor and ACS712 Sensor

Device	Average Current Error (%)	Average Voltage Error (%)
Device Indoor	2.78%	0.086%
Device Outdoor	0.343%	0.343%

Both sensors have acceptable error rates and provide accurate measurement results for current and voltage required in power calculations.

Calculation of Power and Cost of Electricity Consumption

The system performs an automatic calculation of the electric power used and calculates the estimated cost based on the power consumption. These measurements are taken at daily and monthly intervals to provide a broader picture of electricity usage.

1. Daily Electricity Usage Simulation Results
   Average power consumption per day is 5 kWh, with an estimated monthly cost of Rp 250,000.
2. Estimated Energy Savings
   The light automation system results in energy savings of up to 30% compared to manual use.

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Data Visualization on Web Dashboard

Data from sensors is displayed in real-time on the web dashboard. Visual displays in the form of graphs and tables help users easily monitor electricity consumption and lamp status.

1. Electricity Usage Monitoring
   This view shows the power usage in a table, which helps users understand the amount of energy consumption.

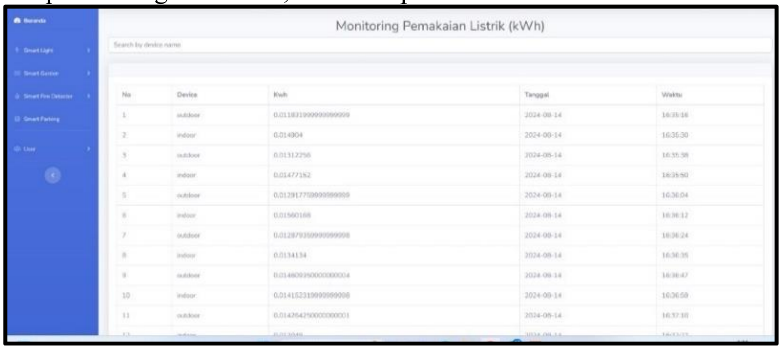

Figure 9. Electricity Usage Monitoring

2. Estimated Electricity Cost Bill
   The dashboard provides automatic calculations for electricity usage costs based on daily and monthly consumption data.

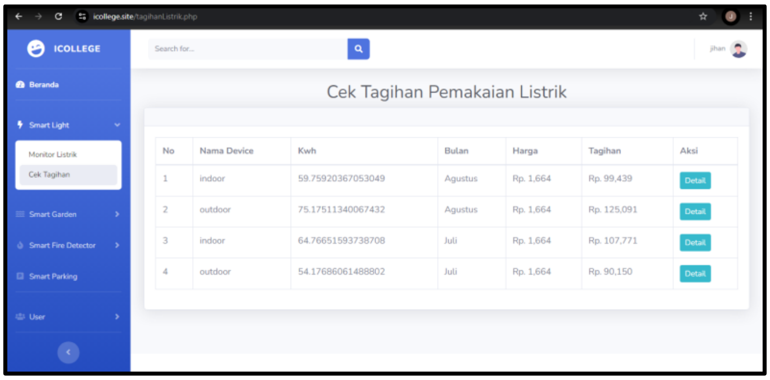

Figure 10. Estimated Electricity Cost Bill

DISCUSSION

Wi-Fi Connectivity Performance on ESP 32

Based on the results of the Wi-Fi connectivity test on the ESP32, the system proved to be able to connect to the WLAN network stably. The serial monitor display shows that both controllers successfully initialize and maintain a connection to the Wi-Fi network, which is an indicator that the devices can effectively communicate over the network.

This success ensures that data can be sent and received over WiFi, which is essential for system operation. However, it should be noted that the stability of the Wi-Fi connection may be affected by external factors, such as distance from the router and signal interference. Therefore, it is recommended to test the system under various environmental conditions to ensure optimal performance.

Effectiveness of PIR and LDR Sensors in Light Automation

The PIR Sensor test results show that this device is able to detect motion within 60 centimeters radium well and provide fast control of room lights. However, the PIR Sensor cannot detect the movement of goods and very fast movements, this is due to the decreased or low ability to read objects and fast movements.

The LDR Sensor Module shows that this device is able to detect the lack of light intensity with 95% accuracy and turn on the corridor lights quickly. However, if there is an object blocking the sensor and making the sensor detect low light intensity, the lights will turn on even though the actual light intensity is high.

Energy Saving Efficiency

Based on the estimated daily and monthly electricity consumption, the lighting automation system resulted in energy savings of approximately 30% compared to the manual method. These savings are in line with the research objective to improve energy efficiency on campus, while helping to reduce operational costs. These findings are in line with research trends in the field of smart lighting, which indicate the potential for significant energy savings through the application of sensors and IoT in lighting management.

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Data Visualization and Ease of Access through Web Dashboard

A web dashboard interface that displays data in real-time makes it easy for users to access information related to energy consumption and lamp status from any device. Graphical displays and cost estimations help users better understand energy consumption patterns and proactively monitor electricity costs. This shows that IoT integration in campus lighting management not only improves efficiency, but also provides transparency to users regarding energy consumption.

CONCLUSION

This research successfully designed and implemented an Internet of Things (IOT)-based Smart Light Electricity Automation and Monitoring System in a Prototype Campus Environment. Based on the test results, several conclusions can be drawn as follows:

1. Connectivity and Sensor System Reliability
   The ESP32 system successfully connected stably to the Wi-Fi network and was able to transmit data in real-time, supporting the electricity monitoring process without interruption. The PIR and LDR sensors showed accurate response in detecting motion and light intensity, which enabled automatic light control according to the surrounding conditions.
2. Energy Measurement Accuracy
   ACS712 current and ZMPT101B voltage sensors provide current and voltage measurement results with low error rates (2-3% for current and 0.08-0.34% for voltage). This shows that the system is quite accurate in calculating the power consumed, thus providing a precise estimation of electricity costs.
3. Energy Savings and System Efficiency: The light automation system resulted in energy savings of up to 30% compared to the manual method. This shows that the implementation of IoT in campus lighting management can reduce unnecessary energy consumption and potentially lower operational costs.
4. Accessibility Through Web Dashboard
   The web dashboard allows users to monitor electricity usage and costs in real-time. This interface increases transparency and ease of access to information for users, which in turn supports efficient energy management.
   Given the results obtained, the system has the potential to be further implemented in a wider campus environment or in other commercial buildings. Further developments could include extending the range of sensors and using more efficient communication protocols to improve the speed and accuracy of data transmission.

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