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Smart Office Implementation System for Electrical Energy Consumption Efficiency Using IoT-Based Fuzzy Algorithm

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Abstract

Increased electricity consumption in office environments often results in waste and inefficient costs. This study aims to develop an Internet of Things (IoT)-based Smart Office system using a fuzzy algorithm to improve electricity efficiency. The method used is the Research and Development (R&D) approach with the Continuous Improvement Spiral model. This system is designed by utilizing a DHT11 sensor for temperature and an LDR for light intensity, which is connected to an Arduino Nano as the main data processor. Data is processed using a fuzzy algorithm to control electronic devices, such as lights and fans, and monitored through the Blynk application. The results showed that the system was able to reduce electricity consumption from 63.57 kWh to 41.32 kWh, with significant savings in monthly electricity costs. The average sensor accuracy reached 99.40% for DHT11 and 96.36% for LDR. This system makes a positive contribution to energy efficiency and is a sustainable solution for office environments.

Keywords: Smart Office; Internet of Things (IoT); Fuzzy Algorithm; Electrical Energy Efficiency; Real-time Monitoring.

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Introduction

Electrical energy plays a very crucial role in everyday life, both in the context of office, industrial, and household activities (Geograf, 2023; Hartechsby, 2024; Kartika, 2018; Nancy, 2023; Khakim et al., 2020; Rahayu, 2016). The presence of electrical energy not only provides comfort but also influences the way humans interact with technology (Erwin et al., 2023; AMA Saputra et al., 2023; Satria, 2023; Lesmana et al., 2024). The widespread use of electrical energy has significantly changed human work patterns and lifestyles (Andriyani et al., 2023; Seneru et al., 2024; Yola, 2020). In modern offices, for example, electricity enables the integration of smart technologies that support productivity and work efficiency (Adriman et al., 2018; Hidayatullah & Juliando, 2017; Nandar, 2024). Likewise, in the household, the presence of electrical devices makes household chores easier and more efficient (Brianorman et al., 2014; Erdin, 2021; Muhammad et al., 2021; Pratama & Wahyudin, 2023). Meanwhile, in the industrial sector, electricity supports automation and the development of advanced technologies that can improve the quality and quantity of production.

Data released by the Ministry of Energy and Mineral Resources (ESDM) shows that in 2022, electricity consumption per individual in the country reached 1,173 kilowatt hours (kWh), an increase of 4.45% compared to 2021, which recorded a figure of around 1,123 kWh (Adi, 2024). Meanwhile, PLN's South Sulawesi, Southeast Sulawesi, and West Sulawesi Main Distribution Unit (UID SulSelbar) noted that until December 2022, the amount of electricity consumption in their operational areas reached 9.54 Tera Watt hours (TWh), a significant increase of around 16.53% compared to the previous year (Kassa, 2023).

The increase in the use of electrical energy also has consequences for increasing electricity bills and the potential for environmental damage due to increased greenhouse gas emissions (Adiputra et al., 2018; Basyiran, 2014; Dincer, 1999; Al-Shetwi, 2022; Farghali et al., 2023; Strielkowski et al., 2021). The government's policy on saving electricity usage as mandated in the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 13 of 2021, underlines the need for stronger efforts to increase energy efficiency (BPK, 2021; Utomo et al., 2021). In this case, actions are needed that lead to a more planned use of electrical energy, taking into account crucial factors such as safety, comfort, and productivity (Hidayat et al., 2024; Nguyen & Aiello, 2013; Omer, 2009; Sulawesi, 2011). The

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Tomakaka Group Department of Education Office (Dirpen Tomakaka) is a real example of inefficient use of electrical energy due to the negligence of employees or staff in turning off electrical equipment such as air conditioners (fans), lights and electrical outlets when they leave the office, resulting in an increase in electricity bills every month.

A number of previous studies have also raised similar issues in an effort to overcome electrical energy waste and optimize energy consumption efficiency. (Alfafa & Bilfaqih, 2020) designed and implemented a smart home with low power consumption using the Cuckoo-Earthworm optimization algorithm. This study provides evidence that the integration of smart technology with optimization algorithms can significantly reduce energy consumption. Other relevant research is the work of (Pramudhita & Mawangi, 2021) about the smart grid for efficient electricity consumption in the production process in the manufacturing industry. This study reveals that the implementation of a smart grid system can ensure efficient energy distribution on an industrial scale, reduce waste, and have a positive impact on operational efficiency. In addition, research by (D. I. Saputra et al., 2019) about the design of a household appliance monitoring and control system using NodeMCU is also an important reference. This study illustrates how controlling household electronic equipment can be done efficiently through Internet of Things (IoT) technology.

This research was developed to be implemented so that it can overcome the problems related to the soaring electricity bills at the Tomakaka Group Department of Education Office (Dirpen Tomakaka). The concept of a smart office has emerged as a solution to optimize the use of electrical energy in an office environment. This system explores the use of Internet of Things (IoT) technology and fuzzy logic to optimize electrical energy consumption by automatically regulating electronic equipment such as fans, lights, and power outlets based on environmental conditions and user needs. With the help of IoT technology, namely Blynk, users can easily monitor the three electrical equipment through their smart devices. It is hoped that the results of this study will make a positive contribution to reducing excessive electrical energy consumption and waste in office environments, as well as promoting the application of sustainable technology in the business and office world.

Method

The type of research used in this study is R&D/Research and Development. R&D research is a type of research that functions to produce something new and is continued with testing it, then the research method used is the Continuous Improvement Spiral Model (Haryati, 2013; Sugiyono, 2015; Waruwu, 2024; Maydiantoro, 2021; Putra, 2012; Safitri et al., 2020). The use of the Continuous Improvement Spiral Model method will allow researchers to face challenges that may arise during implementation, while continuously improving the system to be more efficient and responsive to changing electrical energy needs in the office environment (Adiya et al., 2024; Wiguna & Mahdiana, 2023; Zen & Iswavigra, 2023; Zidniryi, 2022). With this approach, the purpose of this study, namely the efficiency of electrical energy consumption through the implementation of IoT-based smart offices with fuzzy algorithms, can be achieved in a systematic and adaptive manner. The stages are planning, data collection, design, implementation, testing, and analysis.

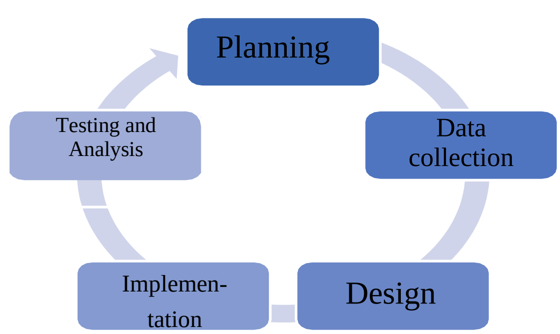


Figure 1. Continuous improvement spiral model

In Figure 1, the research flow begins with the planning stage, where the topic and object of the research are determined, namely the Tomakaka Group Education Department Office, and an initial analysis is carried out on the condition of the office environment and energy efficiency challenges. The data collection stage includes observation, interviews, and literature studies to identify patterns of electricity use, environmental management needs, and user work characteristics. In the design stage, system requirements are analyzed by identifying important variables such as temperature, light, and user presence, and designing a fuzzy algorithm as a basis for intelligent decision making (Ain et al., 2018; Goudarzi et al., 2021; Shah et al., 2019). Next, the implementation stage involves the creation and integration of IoT sensor-based hardware with software that supports fuzzy algorithms, forming a system that communicates with each other. The final stage is testing and analyzing system performance, which involves evaluating functions, responses to various environmental conditions, and energy efficiency before and after implementation, so that the success of the system in achieving energy efficiency can be assessed comprehensively.

This research was conducted through systematic stages that began with a literature study to understand the concept of smart office, IoT, fuzzy algorithms, and electrical energy efficiency, and analyzing relevant previous research. The next stage is system design, which includes the development of hardware and software architecture, such as fuzzy algorithms and Blynk monitoring applications, and the integration of related components. Furthermore, a system prototype was built by implementing hardware, including sensors and microcontrollers, and software logic for automation based on sensor conditions. The trial and validation stages were carried out with various scenarios to test the effectiveness of the system in optimizing electrical power consumption.

The data collected was then analyzed to evaluate energy efficiency and its impact on electricity cost savings. The refined system was implemented in a real office environment to monitor its performance on a production scale. The evaluation was carried out by comparing energy consumption before and after system implementation, followed by the preparation of a research report that summarizes the entire process, findings, and recommendations for further development. The research design is in the form of a system block diagram that aims to create a picture of the implementation of the fuzzy logic method, hardware, and software. Then, a series of tools to facilitate the installation of components on the system created, then a schematic circuit of the system is created.

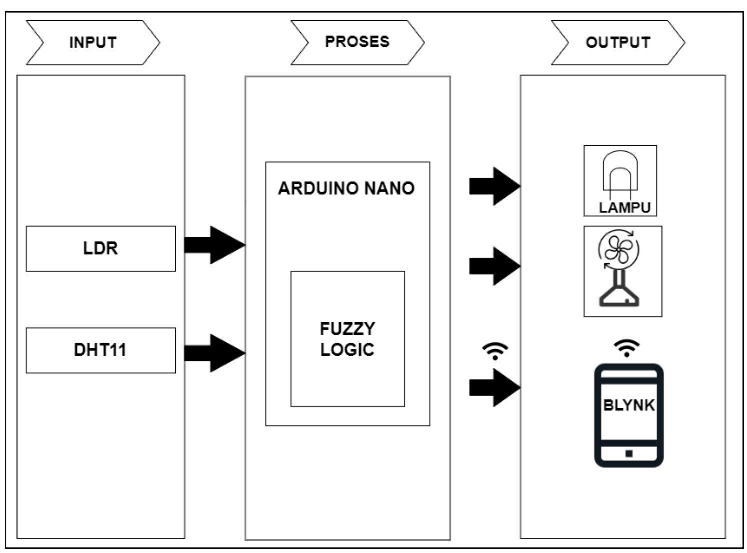


Figure 2. System block diagram

Based on Figure 2, the system design block diagram, the input, process, and output stages are designed as follows: The input stage includes input data obtained from two types of sensors, namely the LDR sensor to detect light intensity and the DHT11 sensor to measure room temperature. This data is then processed using fuzzy logic implemented on the Arduino Nano device to produce the appropriate output. The output stage includes the processing results in the form of controlling two lamps and two fans, with monitoring of sensor data and the condition of electronic devices displayed in real-time via the Blynk application.

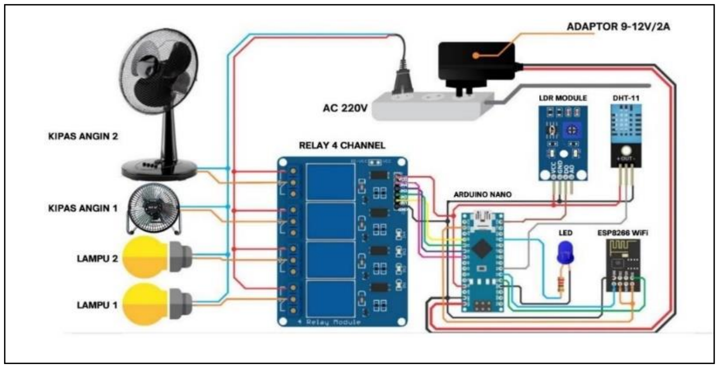


Figure 3. System circuit schematic

In Figure 3, a series of components is used in building a smart office for efficient electricity consumption using an IoT-based fuzzy algorithm. Consisting of 2 (two) lamps, 2 (two) 4-channel relay fans, an ESP8266 wifi module used to send data for monitoring to the Blynk application, and an Arduino Nano as a processing center for sensor input and output of electronic devices connected using a fuzzy algorithm. The entire series is connected using jumper cables, a relay as a current neutralizer to turn electronic devices on and off based on the process generated by the microcontroller, and an adapter as a current connector. The temperature input value on the DHT11 sensor will then be processed by the Arduino Nano microcontroller to be used in the system as a membership function to determine the results and output conditions on the lamp. The temperature input value on the LDR sensor will then also be processed by the Arduino Nano microcontroller to be used in the system as a membership function to determine the results and output conditions on the fan.

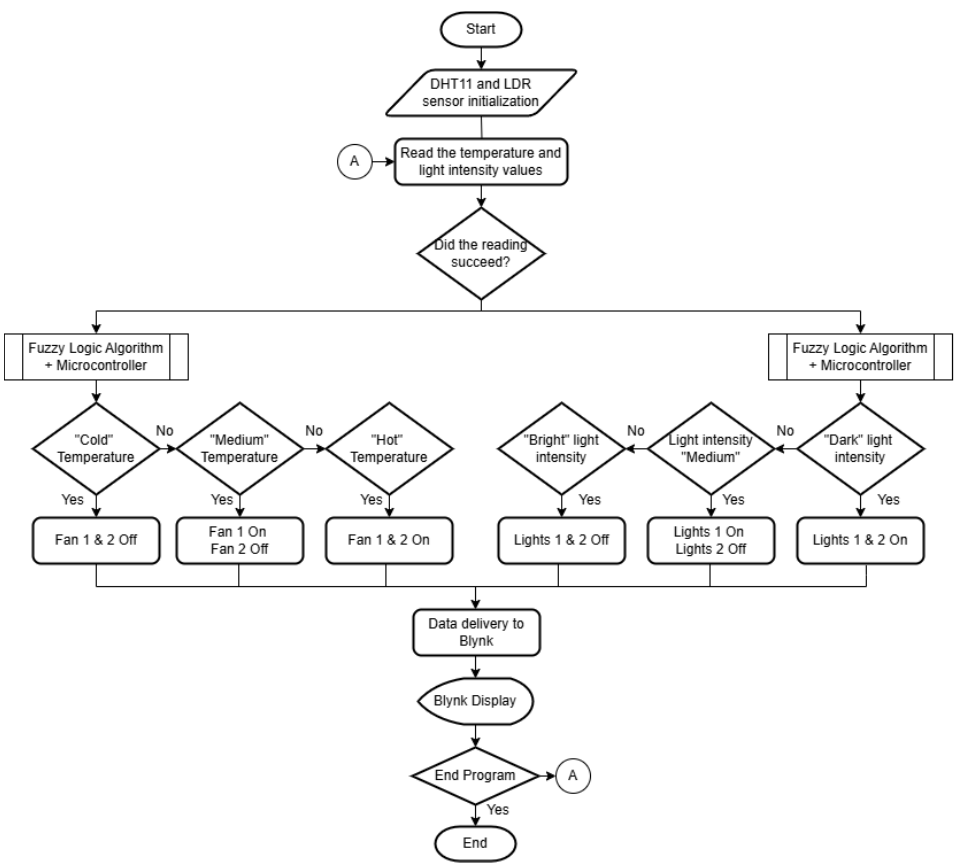


Figure 4. System workflow diagram

The flowchart in Figure 4 explains how the decision-making process on Arduino Uno is based on the fuzzy algorithm that has been formed. When the system is started, initialization will be carried out on the DHT11 sensor and LDR sensor. Both sensors then perform sensing to measure temperature and light intensity. If the reading is successful, the Arduino Nano microcontroller will carry out the decision-making process according to the fuzzy algorithm that has been created. Furthermore, the system will make a decision by checking the condition of the temperature variable if it is "cold", "warm", or "hot", whose output will determine the two fans connected to the system.

Condition checking is also carried out on the light intensity variable if it is "dark", "medium", or "bright", whose output is used to determine the condition of the two lamps. If none of the three conditions in the temperature and light intensity variables are met, the system will re-read the values from each DHT11 and LDR sensor. The results of the decision-making in the form of the condition of the electronic devices of the lamp and fan, as well as the temperature and light intensity values, will be sent and displayed via the Blynk application. The tool system will carry out the measurement process continuously as long as the tool is active. The system is complete when the tool stops working or is in an inactive state.

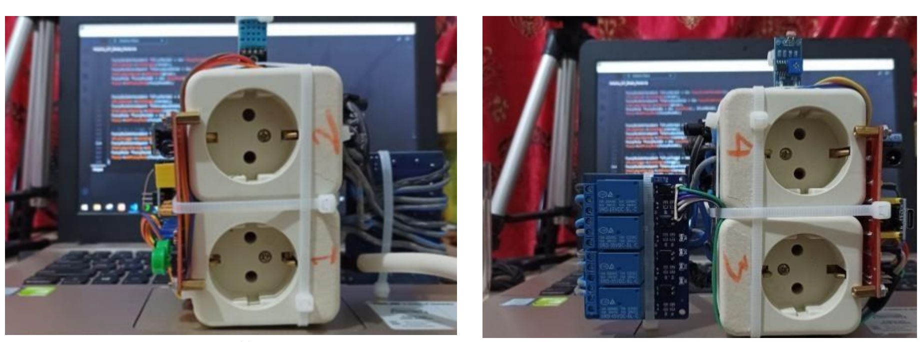
Results and Discussion

Results

Implementation of the design results of the smart office implementation system for efficient electricity consumption using IoT-based fuzzy algorithms:

Figure 5. Microcontroller and sensors

Figure 5 shows the arrangement of components that have been designed, where each device consists of one Arduino microcontroller and two sensors and a power outlet that is the same number as the electronic devices that will be connected.



(i) (ii)

Figure 6. (i), (ii) Socket

In Figure 6, the power outlets that connect the electronic devices to be connected are two lamps and two fans.

Figure 7. Blynk widget display

In Figure 7, the widget is displayed from the Blynk application. The status of electronic devices connected to the system can be seen through the Blynk application. The temperature and light intensity of the room can be seen through the Blynk application, as well as the status of the connected electronic devices. Next is the result of fuzzy logic testing with mathlab, this test is done by comparing the output value of the lamp on the system with the output of the lamp obtained from matlab and then the accuracy calculation will be carried out, in testing the output results of the system and matlab using floating point data types. Table 1 shows the results of the accuracy test.

Table 1. Results of testing the accuracy of the system output with the MATLAB output

Testing of the	System Output Value	Output Value Matlab	Accuracy (%)
1	1003	255	75.58%
2	980	251	75.39%
3	318	101	69.24%
4	439	139	69.34%
5	1020	255	76.00%

Based on Table 1, the average level of accuracy of the lamp output reaches 73.11%. It can be said that the level of system accuracy is quite good. The following figure 8 will show a comparison graph of the system output value with the MATLAB output value.

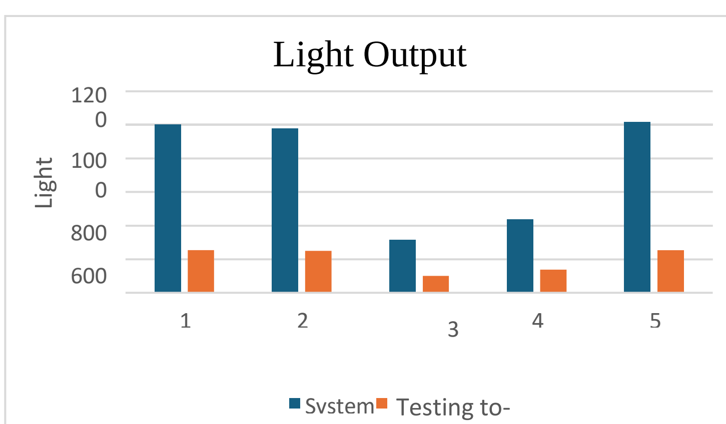


Figure 8. Comparison graph of the system's light output with MATLAB

Testing the output of lights and fans using the domain range or value limits on reading lights and fans, which can be seen in Table 2.

Table 2. List of domain ranges for lights and fans

Name	Mark	Variables	Information
Light	0-400 lux	Low	L 1 and 2 are active
	300-800 lux	Normal	L 1 is on and L2 is off
	700-1023 lux	Tall	L1 and 2 off
Fan	0 – 26 °C	Low	K 1 and 2 off
	27 – 36 °C	Normal High	K1 is on and K2 is off
	37 – 45 °C		K1 and 2 Active

Table 3 contains output conformity testing carried out to determine the conformity of the system fan output with the rules created in the Arduino IDE.

Table 3. Results of fan output suitability testing

Testing of the	Temperature (°C)	Fan Output	Compliance
1	34	Normal	In accordance
2	36	Normal	In accordance
3	40	Tall	In accordance
4	38	Tall	In accordance
5	38	Tall	In accordance

From the tests that have been carried out in Table 3 that everything is in accordance with the rules that have been determined for the microcontroller. This shows that the system can run very well in detecting input and producing appropriate output.

Table 4. Results of lamp output suitability testing

Testing of the	Light (lux)	Light Output	Compliance
1	1003	Tall	In accordance
2	980	Tall	In accordance
3	318	Normal	In accordance
4	439	Normal	In accordance
5	1020	Tall	In accordance

Table 4 contains the Lux lamp output conformity test conducted to determine the conformity of the system output with the rules created in the Arduino IDE. From the test, all outputs produced from the five tests are in accordance with the rules that have been determined in the microcontroller. This shows that the system can run very well in detecting input and producing appropriate output. To analyze the system that has been created, a comparison is made based on the cost of electricity payments in December against the electricity payments in January. Based on the cost of electricity payments, the calculation of electricity consumption during the month is carried out using the formula:

$$Konsumsi\ KWH = \frac{Biaya}{Tarif \times Pembayaran} \quad (1)$$

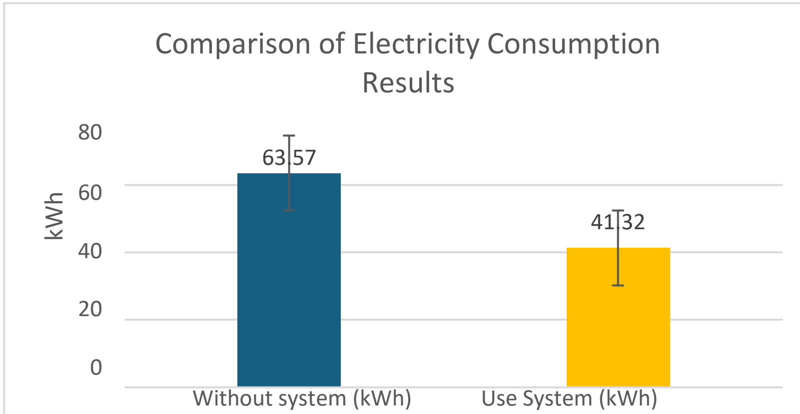


Figure 9. Graph of electricity consumption comparison results

The results of the study were obtained by conducting two tests for two months, namely without a system and each of which was five days during office hours and two days outside office hours for 24 hours. It is known that the electricity consumption data for testing without a system is 63.57 kWh and the electricity consumption data for testing using a system is 41.32 kWh. The picture shows the electricity bill for December 2023 and January 2024.

Discussion

Controlling energy consumption after implementing this fuzzy logic system can be more efficient because the lights, contact stock, and also air conditioners in the form of fans can be turned off automatically when not in use. By using a number of sensors, this system can measure light intensity so that the lights can be turned on automatically according to the light conditions. The number of air conditioners in the form of fans can be turned on automatically according to the room temperature conditions at that time. The result is that the energy consumption of electrical equipment such as lights and air conditioners can be used efficiently every day, as seen from the decrease in electricity payments in the following month when the system is implemented. From Rp. 699,235 to Rp. 454,502.

From the results of the system testing, there is a possibility of errors during parameter measurement. Error factors are a major concern in evaluating system performance, considering sensor measurement uncertainty, environmental variability, data input errors, and the complexity of the fuzzy algorithm. There are significant findings related to the accuracy of the test results, where sensor measurement errors can have a direct impact on the inaccuracy of the estimation of electrical energy consumption. Environmental variability, such as changes in temperature and light, also shows the potential to affect the response of the sensor and the fuzzy algorithm. Through this error factor analysis, this study highlights the importance of careful sensor calibration, fuzzy algorithm uncertainty management, and consistent environmental monitoring. Therefore, optimization of system design and implementation needs to be a deep concern to improve the reliability and accuracy of the system in achieving optimal electrical energy efficiency in the office environment. Improvement steps and recommendations to overcome error factors have been proposed to improve system performance and increase the validity of future test results.

Conclusions and Suggestions

Conclusions

The conclusion of the system testing shows that the implementation of the IoT-based Smart Office system with a fuzzy algorithm for efficient electricity consumption has been successfully created, equipped with a Blynk application interface that monitors the condition of fans, lights, temperature, and light intensity. The test showed savings in electricity consumption, from 63.57 kWh to 41.32 kWh, which resulted in a decrease in electricity costs in January compared to December. In addition, the test results showed an average accuracy of the DHT11 sensor of 99.40% and the LDR sensor of 96.36%, based on a comparison with standard measuring instruments in nine tests.

Suggestions

The suggestions given by the author for further research are as follows:

1. It is necessary to add an RTC sensor to be able to set the time, so that the system can determine itself when outside of working hours.
2. Adding to the kWh calculation system each electronic device connected to the system to obtain more detailed data regarding the electrical energy consumption of the device.
3. Can use other methods on fuzzy logic.

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