# Implementation of an IoT-Based Energy Consumption Monitoring and Control System for Air Conditioners in Boarding Houses

**Gading Aulia[1], Putri Elfa Mas'udia[2*], Rieke Adriati Wijayanti[3]**

[1,3]Digital Telecommunication Network Study Program, Department of Electrical Engineering, State Polytechnic of Malang, 65141, Indonesia

[2]Telecommunications Engineering Study Program, Department of Electrical Engineering, State Polytechnic of Malang, 65141, Indonesia

[1]gadingaulia14@gmail.com, [2]putri.elfa@polinema.ac.id, [3]riekeaw@polinema.ac.id

**Abstract— Electrical energy is a very important basic need in human life. However, the non-renewable natural resources that are often used for power generation can damage the environment. Electricity wastage often occurs due to user negligence. In addition, users often do not have adequate information and tools to properly manage electrical energy consumption. To overcome these problems, this research proposes "Implementation of Monitoring and Controlling System for Electric Power Consumption Based on the Internet of Things (IoT) on Air Conditioner (AC) in Boarding House Environment". This research aims to reduce the waste of electrical energy by implementing an Internet of Things (IoT) based monitoring and control system on air conditioners (AC) in a boarding house environment. This system uses PZEM004T sensor to monitor electric current and voltage, and Microwave Radar sensor to detect the presence of people in the room. With an Android-based application, users can control and monitor AC power consumption as needed. Based on research that refers to daily energy consumption data of 0.97 kWh, it can be estimated that the energy requirement for 1 week is around ± 29.1 kWh, based on the energy consumption patterns of AC devices that have been identified, users can manage electricity purchases according to estimates and ensure the purchase of electricity. carried out based on actual needs.**

***Keywords— Air Conditioner, Android, Electric Power, IoT, PZEM004T, Microwave Radar.***

## I. INTRODUCTION

Electrical energy plays an important role in meeting daily needs, driving various activities in our lives, both in urban and rural and coastal areas. Electrical energy sources such as Diesel Power Plants (PLTD), Hydroelectric Power Plants (PLTA), Gas Power Plants (PLTG), Steam Gas Power Plants (PLTGU), and others have contributed to providing these energy supplies. However, the procurement of electrical energy often requires a large investment and takes a long time. In this context, it can be emphasized that the sustainability of electrical energy supply is a challenge that must be faced together. Although there are various sources of electrical energy available, nevertheless, efforts to develop more efficient and environmentally friendly technologies remain an important agenda. Even though there are various sources of electrical energy available, efforts to develop more efficient and environmentally friendly technology remain an important agenda [1].

According to data from the Central Statistics Agency (BPS) of the Republic of Indonesia in the publication of PLN Statistics 2022, the household sector is the largest contributor to electrical energy consumption in Indonesia with 42.41% of energy sold. The household sector generally includes housing used for private residence, not for commercial or industrial activities such as private residences, apparatus, boarding houses, dormitories and Islamic boarding schools [2].

According to the Great Dictionary of the Indonesian Language (KBBI), a boarding house or boarding house can be interpreted as a place to live (house) that is rented to other people with or without meals (by paying every month), or it can also be interpreted as a residence that is rented to several people with a monthly distribution system. The Central Statistics Agency (BPS) of Indonesia has conducted a survey on the housing patterns and preferences of the Indonesian people. In the 2021 Housing and Building Statistics report, BPS highlighted that boarding houses are a common type of housing among young adults. The report shows that 11.6% of households in Indonesia are boarding houses, with a higher concentration in the younger age group [3].

Public facilities of boarding houses generally refer to facilities provided and can be shared by all boarding house residents. These facilities are usually provided by the owner or manager of the boarding house such as bathrooms, kitchens, parking areas, living areas and security as well as facilities in the boarding room refer to the equipment and equipment provided in the room to support the comfort of residents. These facilities vary depending on the type and price of the boarding house, including beds, cabinets, tables and chairs, fans, internet networks and also air conditioners.

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In the household sector, especially boarding houses, the use of air conditioners is one of the main contributors to electrical energy consumption rather than several other electronics such as fans, rice cooker and lights, in a survey from PT PLN (Persero) (2021) around 30% of electrical energy consumption in boarding houses in Greater Jakarta comes from the use of air conditioning [4].

Given the significance of air conditioning energy consumption in boarding houses, proper energy management is essential to address these issues. In the current era of technological adoption, it supports the existence of the right solution by utilizing the Internet of Things (IoT). With the adoption of IoT technology, energy management in boarding houses can become easier and more scalable. IoT enables real-time monitoring of energy consumption, so it can identify suboptimal usage patterns and provide better control over air conditioning devices. Thus, boarding house residents can take the necessary steps to optimize energy use. In other words, the use of IoT technology in managing air conditioning energy in boarding houses not only provides control over electrical energy consumption, but also reduces operational costs from the pattern of using air conditioning devices. This is in line with efforts to create a more sustainable and environmentally friendly residential environment [5].

Based on the formulation of the problem, the purpose of this study is to design and implement an IoT-based electrical energy consumption monitoring and controlling system on Air Conditioner (AC) devices in boarding houses, monitor and manage electrical energy consumption on Air Conditioner (AC) devices independently using Android-based applications, and evaluate the success of IoT-based electrical energy consumption monitoring and controlling systems in reducing AC electrical energy consumption in the boarding house.

In the previous study, design research that combines Internet of Things (IoT) technology with Sugeno's Fuzzy Logic algorithm in an electrical power monitoring system that can be controlled through an Android application. The monitoring developed in addition to seeing the interface of the electricity monitoring results used by hardware tools through smartphones by looking at electricity bills, electricity power and electricity prices at a user-determined time, in the study was developed electricity use features with low, medium and high user output using the Sugeno's Fuzzy logic algorithm as a decision maker, the output of the results is in the form of graphs to make it easier to read the final result. The output in the Android application displays a breakdown of electricity in the form of a table of the amount of electrical energy and electricity costs according to the date request that the user wants to see [6].

The creation of a system used to monitor the electrical power used. The system is designed using a NodeMCU module that will be paired with a PZEM-004T sensor and a relay. NodeMCU functions for sending data to the database. The PZEM-004T sensor is used to read the voltage and current flowing so that the power value can be obtained. The relay is used as a control to disconnect the electrical connection if necessary. To be able to find out the electrical power, the electrical power data will be sent to the Realtime Firebase Database which will be monitored by Android devices via the internet so that this monitoring can be done remotely. The results of the system application test show that the application can monitor the power in each boarding room in real-time [7].

In the journal "Measurement of Electrical Energy Based on PZEM-004T" it is proposed to measure electrical energy with the PZEM-00T sensor, by using the PZEM-004T sensor the resulting tool is quite simple, because the PZEM-004T sensor has a current and voltage sensor to display the readings on a 20x4 LCD screen and it is controlled by an Arduino. After the tool is made, the result is a voltage measurement error of 0.2% and a current measurement error of 0.2% [9].

Previous research has had several significant limitations. First, the control or control to disconnect the electrical connection is done manually using an Android app, which is one of the weaknesses in this study. Second, this study only compares the results of voltage and current measurements using the PZEM-004T module and clamp tester, so this is one of its weaknesses. Third, the system can only monitor the electrical energy displayed in the Blynk and LCD applications, but it does not have controls to limit the use of electrical energy to be used appropriately.

In this study, the monitoring and controlling system developed is focused on monitoring electrical energy consumption in Air Conditioner (AC) electronic equipment to manage electrical energy consumption in the boarding house. By using a Microwave Radar sensor that functions to detect the presence of people in the boarding house and a PZEM004T sensor that reads the energy consumption used in the air conditioning device. Based on the data obtained from the Microwave Radar sensor, it will make a decision to turn off the air conditioner when there are no people in the room. In addition, this study also emphasizes the control of electrical energy consumption in air conditioning devices and real-time monitoring of electrical energy consumption through an Android application, with an interface that makes it easier for users to see the amount of electrical energy consumption on Air Conditioner devices.

Electrical energy is a form of energy produced by the flow of electrons in an electrical circuit. It is the most common and widely used form of energy in everyday life. Electrical energy can be produced from various sources, both from conventional energy sources and renewable energy sources. Once generated, electrical energy can be channeled through the electrical distribution network for use by consumers in homes, businesses, or industries [9].

kWh is an acronym for kilowatt hour or kilowatt hour, this unit indicates a power consumption of 100-watts per hour. kWh is also commonly used to measure electricity bills, the higher the kWh meter number, the greater the amount of fees that must be paid [10].

According to ITU-T Y.2060 recommendations, the Internet of Things (IoT) is defined as an invention that can solve existing problems by combining technology and social impact. According to technical standardization, the Internet of Things (IoT) can be described as a global infrastructure that meets people's information needs and enables advanced services based on existing and evolving information and communication technologies (ICTs) with physical and virtual connections [11].

ESP32-DEV-KIT, as shown in the Figure 1, is a small-sized ESP32-based development board manufactured by Espressif. Most of the I/O pins are broken down into pin headers on both sides for ease of interface. Developers can connect peripherals with jumper cables or install the ESP32-DEV-KIT specification is on the board.

ESP32-DEV-KIT has advantaged that Arduino does not have, including having WiFi and Bluetooth 4.2 features that are already embedded in the board itself [12]. Then this ESP32-DEV-KIT has a fairly fast processor speed that is already Dual-Core 32-bit with a speed of 160/240 MHz [13].

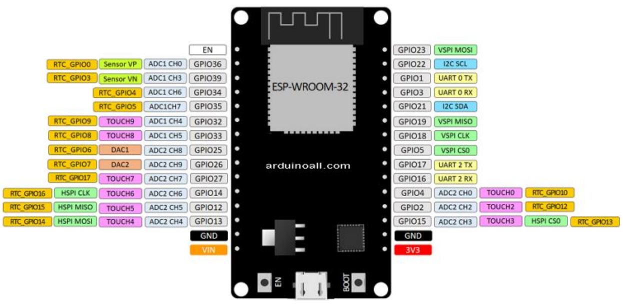



Figure 1. Microcontroller ESP32

The PZEM-004T module, as shown in the Figure 2, is a multifunctional sensor module that functions to measure the power, voltage, current and energy contained in an electrical current. This module is equipped with an integrated voltage sensor and current sensor. In its use, this appliance is specifically for indoor use and the installed load is not allowed to exceed the set power [14].

PZEM004T sensor is a very useful solution in the research and development of electrical energy consumption monitoring projects in Air Conditioner (AC) equipment. PZEM004T enables the measurement of electrical energy by a non-intrusive method, offers a wide measurement range, and produces easily accessible data output. In addition, the calibration capabilities of these sensors improve measurement accuracy.

Operating at a frequency of 24 GHz and utilizing Infineon Doppler radar technology, the Microwave Radar Sensor offers an ideal solution for a wide range of applications, including smart homes, smart hotels, and hazard alarm systems.


Figure 2. PZEM004T Sensor

The sensor is designed to detect human presence with high accuracy, while the integrated standard algorithm provides a fast and accurate response [15].

Figure 3. Microwave Radar Sensor

Arduino IDE is a multiplatform software used to create and upload program code to the Arduino board. The Arduino IDE has many functions and libraries that can be used to develop various electronic projects, including Android-based electrical monitoring projects. The data generated by these sensors can then be sent to an Arduino microcontroller board that is connected to a WiFi network.

In this study, the Arduino IDE was used to develop the program code applied to the ESP32-DEV-KIT microcontroller. The utilization of the Arduino IDE includes writing code that can read voltage and current data from PZEM004T sensors and detect the presence of people in the boarding house using sensors Microwave Radar (as shown in the Figure 3). Next, the data from the sensor Microwave The obtained radar will be processed, the results of the process will be sent and stored in the database Firebase [16].

Firebase is a service Google which provides convenience and even makes it easier developer in developing applications. Firebase or BaaS (Backend as a Service) is the solution offered Google which speeds up the work developer. With Firebase, app developers can focus on app development without having to do a lot of work in the background [17].

## II. METHOD

This research can be classified as development research. The research aims to develop an Internet of Things (IoT)-based electrical energy consumption monitoring system for energy management in Air Conditioner (AC) devices in boarding houses. The study combines the use of PZEM004T sensors, Microwave Radar sensors, and Firebase-connected ESP32-DEV-KIT as data storage platforms. The energy consumption data of air conditioning devices collected from PZEM004T sensors is processed and presented through an Android-based application, which gives users the ability to control the energy consumption of their air conditioning devices through an easy-to-use interface. This implementation is expected to contribute to the management of energy consumption and provide a controlled experience for users in the boarding house environment.

### *A. Research Stages*

The research stages in the implementation of an IoT-based electrical energy consumption monitoring and controlling system for the management of electrical energy in Air Conditioners (AC) in boarding houses can be explained as follows:

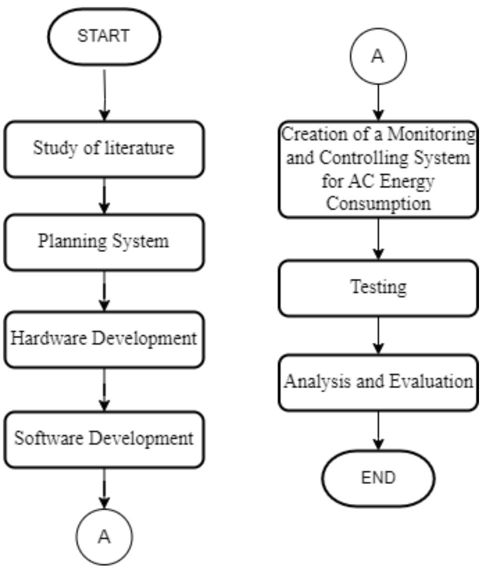



Figure 4. Research Stages

Figure 4 explain about research began from the literature study stage which involved searching for references from several journals, articles and theses or research that had been published from various sources regarding the monitoring and controlling of electrical energy which would then be developed. The next stage is system planning involving the design of the overall structure of the system, including in the selection of hardware, in this case using PZEM004T sensors, Microwave Radar and ESP32-DEV-KIT sensors and software in the form of Android-based applications. This planning includes how the components will interact with each other. The hardware development stage, at this stage, includes the process of connecting or assembling hardware, namely PZEM004T sensors, Microwave Radar sensors and ESP32-DEV-KIT. This stage also involves the connection between hardware and installation in the boarding house. In software development, the main focus is on code writing and testing. It includes system configuration and Android app code writing to control and monitor the energy consumption of air conditioners. Integration with Firebase is done for data management and connection to Android apps. Next is the stage of creating a monitoring system and controlling AC energy consumption, this stage includes the connection between the hardware and software that has been developed, creating a comprehensive monitoring and controlling system that is connected to Firebase as a database. At this stage, the monitoring and controlling system of AC electrical energy consumption begins to operate and can be tested for functionality. Testing is carried out to ensure that the entire system is functioning as expected. This includes testing functionality, reliability, as well as testing in boarding environments. These tests help identify and fix potential problems and shortcomings of the system. The last stage is analysis and evaluation, at this stage it aims to evaluate the performance and results of the Internet of Things (IoT)-based monitoring and controlling system for electrical energy consumption. This stage involves data processing, test results, and a thorough analysis of system performance.

### *B. System Planning*

The design of this system is divided into 3 sub-chapters, namely tool design, application design and database design.

#### *1) Tool Planning*

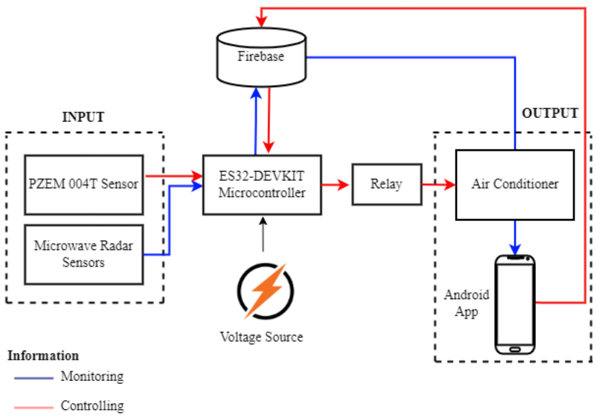



Figure 5. Block Diagram

Tool design is a stage in system development that is more focused on hardware development. The design of the tool includes the creation of diagram blocks, flowcharts and wiring. In Figure 5, a block of diagrams is presented that provides an overview of the Internet of Things (IoT)-based monitoring and controlling system for electrical energy consumption. Here is the explanation

1. The PZEM004T sensor will be connected to the ESP32-DEV-KIT which serves as an energy reading

2. The Microwave Radar sensor is connected to the ESP32-DEV-KIT which functions to detect the presence of people in the room, if the presence of people is not detected, the air conditioner will go out using a relay as a switch.
3. The ESP32-DEV-KIT is connected with a voltage source of 3.3V-5V.
4. The electrical energy reading data from the sensor PZEM004T stored by Firebase as a database that can be accessed through the Android app.
5. This application can monitor the electrical energy consumption of air conditioning devices and can make electricity purchases.
6. The purchased electricity will be stored in Firebase and then ESP32-DEV-KIT will make a comparison between the value of the purchased electricity and the energy used.
7. If the energy consumption of the air conditioner exceeds the purchased electricity, the air conditioner will go out, and if the energy does not exceed the purchased electricity, the air conditioner can be used according to the readings from the Microwave Radar sensor

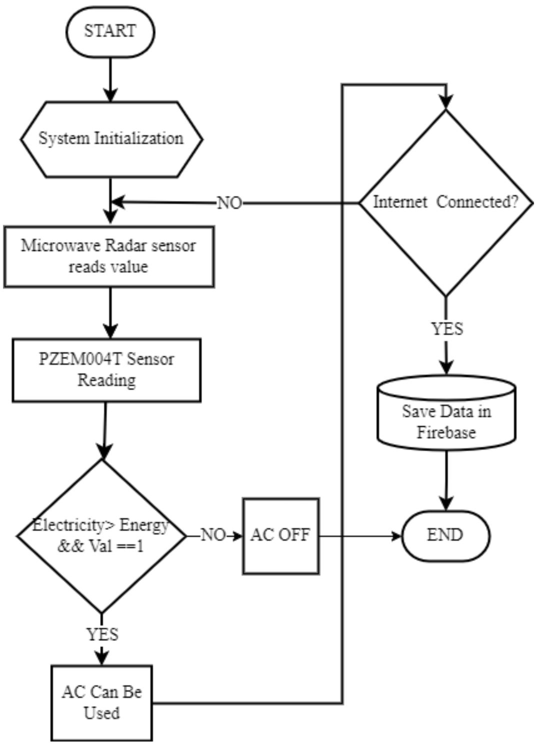



Figure 6. Flowchart System

In the design of the tool, a flowchart or flow diagram is made that represents the algorithm or sequential instruction steps in the system. Figure 6 is the flowchart of the Internet of Things-based air conditioning energy monitoring and controlling system in the boarding house environment

In Figure 6 the system flowchart has the following workflow:

1. 'Initialization process, where the entire system is prepared to start the process.
2. The PZEM004T sensor plays a role in reading electrical energy consumption data from air conditioning devices.
3. Electrical energy consumption readings will be stored in Firebase.
4. The Microwave Radar sensor acts as a detection of the movement and presence of people in the boarding house.
5. The data from the Microwave Radar sensor and the sensor PZEM004T process using predetermined rules, namely in the condition when the energy consumption< electricity, the user can use the air conditioner, and in addition to these conditions the air conditioner will go out, and when there is no one in the room and the air conditioner is in the ON condition, it will automatically go out.

*2) Application Design*

The app is designed to provide easy access to real-time data on energy usage, providing precise control over air conditioning energy consumption. This application consists of two types of users, namely tenant users and owners.

Figure 7 Flowchart of the Owner User Application will show the interaction flow and features available to the owner, which includes registration, monitoring, transactions and recapitulation of electricity on AC devices.

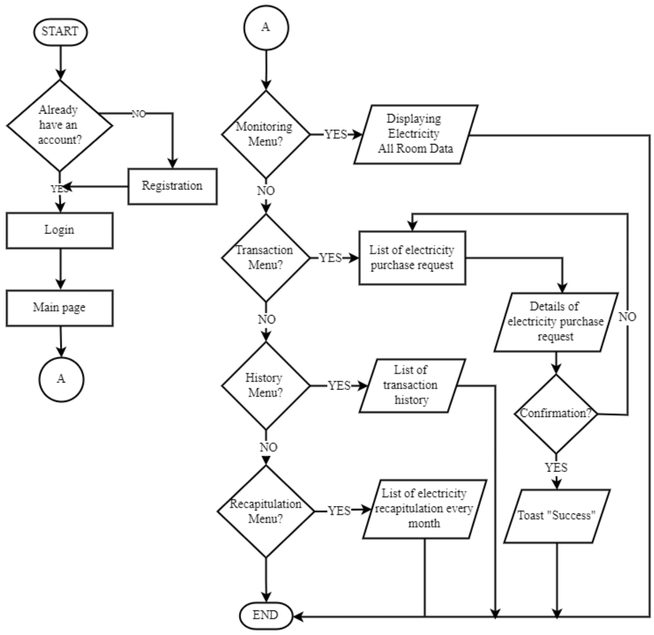



Figure 7. Flowchart of User Owner Application

Figure 7 Flowchart User Owner shows that users must first register and log in to access the application. After logging in, the owner user can access four main menus: Monitoring, which displays electrical energy consumption air conditioning for all rooms in real-time; Transactions, which allow confirmation or rejection of requests to purchase electricity from tenant users;

History, which contains a list of approved electricity purchase history; and Recapitulation

Figure 8 The Tenant User Application Flowchart will illustrate the process that the tenant user goes through, starting from the registration search, the application for the purchase of electricity, to the history of the purchase of electricity.

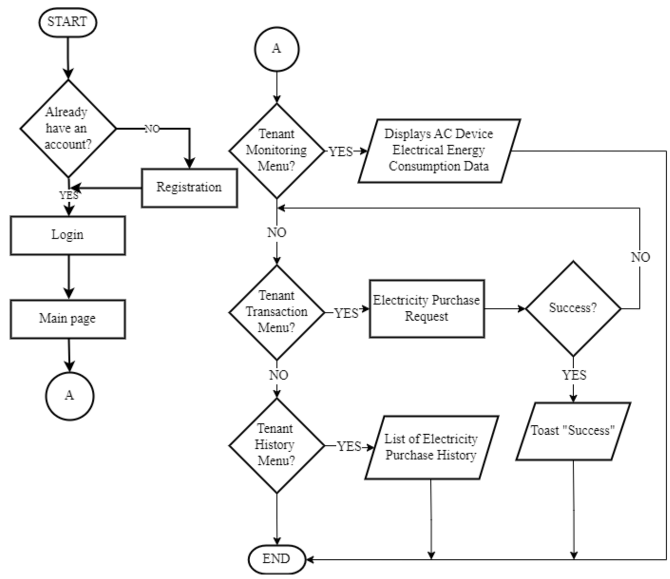



Figure 8. Flowchart User Tenant

In Figure 8 of the Tenant User Application Flowchart, the user will register first, then log in to access the application. After logging in, tenant users have access to three main menus. The Monitoring menu displays the AC electrical energy consumption in the room used in real-time. The Transactions menu allows tenants to submit a request to purchase electricity to the owner user, which will then be verified and approved by the owner. The History menu contains a list of electricity purchase history that has been approved by the owner user.

## C. System Implementation

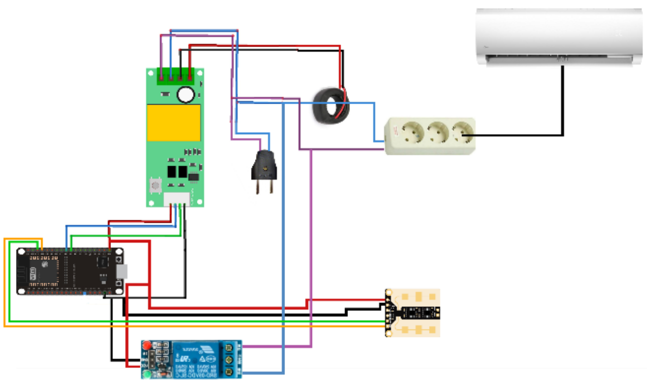


Figure 9. Implementation of System

The implementation of the tool and the placement of the tool system include the installation of PZEM004T sensor components, Microwave Radar sensors, relays connected to microcontrollers and connected to Air Conditioner (AC) devices. Figure 9 is the set implemented.

# III. RESULTS AND DISCUSSION

This chapter discusses the results of hardware and software build and testing implementations, which include activities, application functionality testing, and database management on the Firebase platform. In addition, this chapter also discusses communication testing and data transfer from hardware to Firebase databases.

## A. Tool Manufacturing Results

In this section, the results of the research including sensor calibration and assembly of the tool consisting of ESP32 DevKit, PZEM004T sensor, Microwave radar sensor, and relay have been successfully completed. The tool has been tested to ensure that all components are properly functional and integrated. In Figure 10 is the component that has been installed and connected with the microcontroller. The following is an explanation of the results of making the tool in Figure 10:

1. An adapter port of 5V, 3A is used as the main voltage source to provide power to the entire system.
2. The 5V voltage from the adapter port is used to supply voltage to the PZEM004T sensor. These sensors are responsible for measuring electrical parameters such as voltage, current, power, and energy used or generated by connected electronic devices.
3. The sensor PZEM004T connected to the ESP32 microcontroller using serial communication. The Serial2 pin on the ESP32 Dev Kit is used for this serial communication, where the GPIO25 pin is used as the receiver (RX) and the GPIO26 pin is the transmitter (TX)
4. Connecting the phase wire to the input terminal on the CT module, the CT module can detect the electric current flowing through the cable and transmit the current information to the PZEM004T sensor.
5. The 1-channel relay functions as an electronically controlled switch. This relay is used to control the flow of electrical power to the Air Conditioner (AC) device. The relay is connected to the ESP32 microcontroller via the GPIO15 pin. This allows the ESP32 to control when the relay should be on (ON) or off (OFF), according to the program logic. The relay is connected with a phase wire from the outlet to control the electric current
6. The Microwave Radar (DFRobot_mmWave_Radar) sensor functions to detect presence or movement in the environment. This sensor is connected to the ESP32 microcontroller via serial communication. This sensor is connected to the ESP32 via the Serial1 pin. On the ESP32 Dev Kit, the Serial1 pin is connected to the GPIO25 (TX) and GPIO26 (RX) pins. Thus, the ESP32 can receive data from the sensor and respond according to the information received from the radar Microwave sensor.

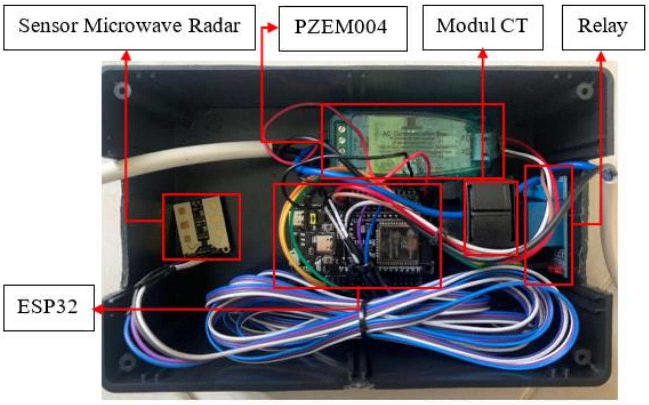
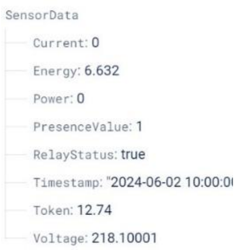
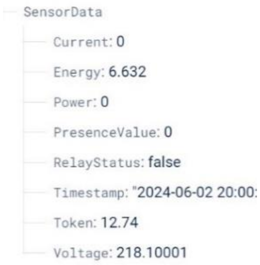


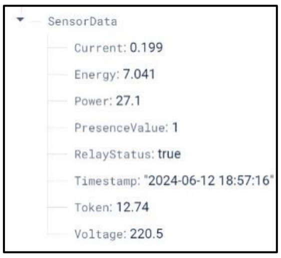
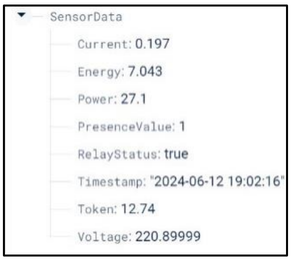
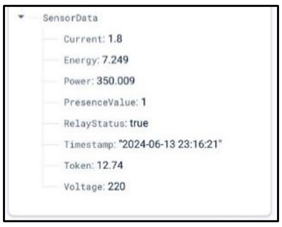
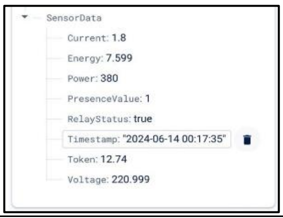

Figure 10. Tool Manufacturing Results

### *B. Testing and Discussion of Tool Data*

In this section, we will outline the results of the tests carried out on the developed tools. Data analysis includes evaluating the performance of the tool as well as the successful communication between the tool and the Firebase database. In testing this tool, there are several conditions applied to be able to turn on and off the Air Conditioner (AC) device automatically. In this test, it was carried out under 5 different conditions. Here is Table 1 which contains the conditions performed during the test.

TABLE I
TOOL TEST RESULTS

| No. | Condition | Test Results | Documentation |
|---|---|---|---|
| 1. | Energy consumption < total electricity && people detected | Based on the results of the tests carried out, when the energy reaches 6,632 kWh and the number of available electricity is 12.74 kWh, and the presence of people in the room is detected, the system will activate the relay so that the AC device can be used. |    |
| 2. | Energy consumption < total electricity && No One | Based on the results of the tests carried out, when the energy reaches 6,632 kWh and the number of available electricity is 12.74 kWh, and the presence of people in the room is not detected, the system will turn off the air conditioning. |    |
| 3. | Energy consumption < total electricity && No One | Based on the results of the tests carried out, when the energy reaches 6,632 kWh and the number of available electricity is 5.5 kWh, and the presence of people in the room is detected, the system will turn off the air conditioning. |    |
| 4. | Energy consumption < total electricity && No One | Based on the results of the tests carried out, when the energy reaches 6,632 kWh and the number of available electricity is 5.5 kWh, and the presence of people in the room is not detected, the system will turn off |  |

| No. | Condition | Test Results | Documentation |
|---|---|---|---|
| | | the air conditioning. |  |
| 5. | Internet Outage | When the internet/Wi-Fi condition is disconnected, the energy consumption reading by the PZEM004T sensor will still be carried out and the microwave radar sensor will also continue to read the presence and absence of people in the room, but for data transmission to Firebase will be done when connected to the internet. | • Conditions before internet disconnection<br><br>• The internet was disconnected for ± 5 minutes with energy consumption < electricity conditions and someone was detected<br><br>• The internet was disconnected for ± 30 minutes with energy consumption < electricity conditions and someone was detected<br>• The internet was disconnected for ± 1 hour with energy consumption < electricity conditions and someone was detected.<br><br> |

The test results show that the developed device is able to operate according to the predetermined scenario, which is to automatically regulate the use of air conditioning based on the level of available energy (expressed in electricity) and the presence of people in the room. The system has proven to be responsive to changing environmental conditions, prioritizing energy use based on top priorities. In addition, the success of communication with the Firebase database is also verified, indicating that the tool can send data for the processing of the necessary information.

### C. *Testing and Discussion of Application Data*

In this sub-section, the results of the application trials that have been developed will be evaluated. The designed application consists of two use cases, which are shown in Figure 11 and Figure 12. Application data testing parameters include:

1. App Functionality Test
   The application functionality test aims to ensure that the application operates according to the specifications that have been set, and that all of its features and functionality are running properly.
2. Test Application Performance in Communication with Database
   Ensuring that the application can handle the process of storing data properly into the Database.


Figure 11. Application on Tenant Users

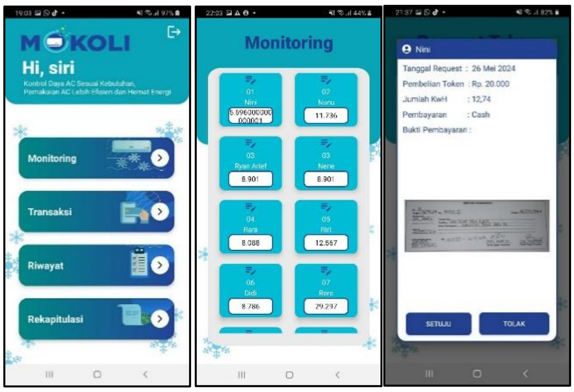



Figure 12. Application on User Owner

TABEL II
ENERGY CONSUMPTION FOR A WEEK

| Date | Total Energy Consumption (kWh) |
|---|---|
| 27/05/2024 | 1.58 |
| 28/05/2024 | 1.35 |
| 29/05/2024 | 1.05 |
| 30/05/2024 | 0.7 |
| 31/05/2024 | 0.525 |
| 01/06/2024 | 0.525 |
| 02/06/2024 | 1.05 |

Based on the results of the application test, it was found that the MOKOLI application was functioning properly and all data was stored in the Cloud Firestore. Based on testing electrical energy consumption data on air conditioning devices for 1-week, daily energy consumption can be calculated in Table 2. So, the average daily energy consumption calculated using Equation (1) is:

$$\text{average} = \frac{\text{amout of data}}{\text{lost of data}} \qquad (1)$$

$$\text{average} = \frac{6.78}{7}$$

$$\text{average} = 0.97 \text{ kWh}$$

Based on the average daily energy consumption obtained of 0.97 kWh, it can be estimated that energy needs will be needed in a longer period.

- 1 week's requirement = (±)6.79 kWh
- 1 month's requirement = (±)29.1 kWh

By purchasing electricity according to estimates, users can ensure that the energy consumption of AC devices is sufficient based on the consumption patterns that have been identified and ensure that the purchase of electricity is carried out based on actual needs.

## IV. CONCLUSION

Based on the research on the implementation of an IoT-based monitoring and controlling system for air conditioner (AC) energy consumption in boarding houses, it can be concluded that the developed system successfully enables real-time monitoring, control, and management of electrical energy usage through internet connectivity, with data securely stored in Cloud Firestore. The MOKOLI application allows users to purchase electricity, view real-time energy balances, analyze consumption patterns, and access usage history, showing an average AC energy consumption of 0.97 kWh per day, equivalent to approximately 6.79 kWh per week and 29.1 kWh per month. System testing indicates that the application performs reliably, with all features—from user registration to transactions and monitoring—functioning as intended, providing easy access to information and effective data management for both tenants and boarding house owners.

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