
Electrical Energy Consumption Monitoring System for Boarding Rooms Using IoT and Progressive Web Application

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Abstract — Energy efficiency has become an essential aspect of sustainable living, particularly in boarding facilities where electrical usage is often uncontrolled and inefficient. This study presents *Molection*, an Internet of Things (IoT)-based system designed to monitor and control electrical energy consumption in boarding rooms by integrating sensors, microcontrollers, and a Progressive Web App (PWA). The system collects real-time data on voltage, current, power, and energy consumption using the PZEM-004T sensor module, which communicates with an ESP32 microcontroller. The collected data are transmitted to a cloud database and displayed via a responsive web interface accessible from various devices. The results indicate that the system provides effective real-time monitoring, with a measurement accuracy of 98.3% compared to standard electrical meters. This study demonstrates that implementing IoT and PWA technologies can support efficient, transparent energy management, especially in shared or rented residential spaces.

Keywords – IoT, energy monitoring, smart meter, progressive web app, boarding room

I. INTRODUCTION

The number of university-level students in Indonesia increases annually. In 2012, the number of students in Indonesia was 6.23 million, while in 2022 it grew rapidly to 9.32 million [1]. The dominance of the student population in 5 large provinces in Indonesia: Banten, East Java, West Java, DKI Jakarta, and Central Java [2].

With the student population continuously growing each year and spread across Indonesia, it is found that not all students come from the same city as their university; many come from other cities. This results in an increased need for student housing during their studies in a particular city. Consequently, the boarding house (kamar kos) rental business has become one of the business sectors with high prospects in the current era of development.

However, in this high-prospect boarding house rental sector, a significant problem persists with the management of electricity consumption in the rooms. Boarding house occupants often use various electronic devices in their rooms without knowing or considering how much electricity they consume, resulting in inefficient energy use. The use of devices such as lights,

air conditioning systems, water heaters, and other electronic devices in boarding rooms can significantly increase electrical energy consumption.

Research on IoT-based monitoring of electrical energy consumption in boarding rooms has been extensively conducted previously. These studies have similar methods and working principles. However, each study has different constituent components and applications, which provide specific advantages and disadvantages to the IoT-based monitoring system.

Based on research by [3], the components and application used were NodeMCU as the microcontroller, ZMPT101B as the voltage sensor, ACS712 as the current sensor, and Cayenne as the display and control for the monitoring system. The system developed in this study included a prepaid mode that estimated the remaining electricity balance on the kWh meter and a postpaid mode that estimated the costs the user would pay for the energy consumed.

According to research by [4], the components and applications used were an Arduino Uno as the microcontroller, a Wemos D1 Mini as the Wi-Fi module, a ZMPT101b as the voltage sensor, an ACS712 as the current sensor, and Thingspeak as the display for the monitoring system. The system

developed in this research was equipped with power, current, and voltage graphs that users could monitor, with measurements that were relatively good and precise. However, this system could only provide output data for monitoring power usage, so the user could not yet monitor current and voltage.

Moreover, based on research by [5], the components and applications used were NodeMCU as the microcontroller, a Pzem-004t sensor to measure current, voltage, power, and energy, and a Relay as an electrical switch for the system. It was also equipped with an Android-based application powered by Firebase, serving as the primary application for monitoring and controlling electricity in the boarding house. This system's main advantages were a 'history' feature in the application that could provide information on power consumption at specific times, and the ability to automatically cut off power via menu options in the application. However, the system developed in this study had a drawback: it was unable to issue warnings to the user via a smartphone when the user exceeded a specified electricity consumption limit.

In the research conducted by [6], the components and applications used were NodeMCU as the microcontroller, Pzem-004t as the current, voltage, power, and energy sensor, and Blynk as the display for the monitoring system. This prototype could monitor electrical energy consumption and was equipped with a feature that could cut off the electrical current via a smartphone if needed, using a relay component connected to the power source. It was also equipped with an electricity credit top-up feature that decreased as the energy was consumed and could provide reminders to pay the electricity bill at certain times. However, the system in this study could not yet display graphs of current, voltage, and power consumption, making the monitorable data incomplete.

Moreover, whereas the research by [7] used the ESP32 as the microcontroller, Pzem-004t as the sensor, and Blynk as the display for the monitoring system, the system created in this study could monitor energy consumption and was equipped with a billing report feature that provided information on the amount of energy used and the total cost to be paid.

However, without an adequate monitoring system and understanding of their energy consumption, occupants tend to overlook or even ignore their electricity usage. This not only impacts their own electricity bills but also contributes to a larger energy burden on power resources and the environment.

Based on this problem, an idea emerged to create an IoT-based electrical energy consumption monitoring system for boarding rooms, named Molection (Monitoring Electrical Energy Consumption). This system can monitor energy use in real time and provide clear, informative insights, making it easier for both managers and occupants to manage electrical energy consumption.

II. RESEARCH METHOD

Molection was developed through 6 main stages: system design, electronic circuit design, 3D design, interface design, and performance measurement methods.

A. System Architecture

Fig. 1 shows the algorithm for the IoT- and PWA-based electrical energy consumption monitoring system. System initialization begins when the system is plugged into a power socket. The electricity enters through the Pzem-004t sensor, which detects the resulting current, voltage, and power. Then, the system calculates the recorded power multiplied by the usage time.

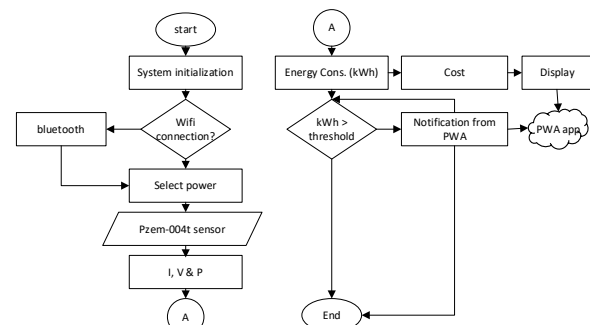


Fig. 1 System design flowchart

The system has a threshold that can be set in the application based on user needs. When the system detects that power usage exceeds a threshold, it will send a notification to the smartphone via the PWA application.

B. Electronic Circuit

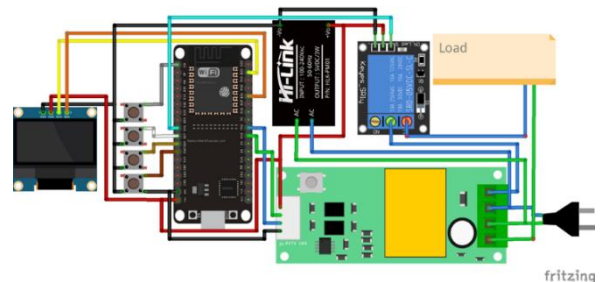


Fig. 2 Molection electronic diagram

Fig. 2 shows the electronic circuit results of the Molection system. This system is designed to connect directly to an AC 100~220V 50 Hz voltage source, with a maximum current of 10 A. The system's design includes five main components: an ESP32 microcontroller, a PZEM-004T sensor, an OLED screen, a relay, and a HiLink module.

Each component plays a vital role in ensuring the system's performance and reliability. Additionally, the system is equipped with various pins that function to control different aspects of the Molection system's operation. The Esp32 microcontroller serves as the system's brain, controlling the PZEM-004T sensor, which monitors voltage, current, and power.

The OLED screen displays data in real time, allowing the user to monitor the system's condition easily. The relay functions as an electronic switch that can control the flow of electricity, while the Hi-Link module provides stable power to the entire system.

The system operates using an AC 100~240V source from PLN (state electricity company), which is converted to 5VDC/3W by the hi-link, acting as a converter, enabling the system to work correctly. The input to the Molection system is from the Pzem-004t sensor, which measures voltage, current, power, and energy. The measurement data is then forwarded to the ESP32 microcontroller for processing and subsequently displayed on the OLED as the system's output, based on measurements from the Pzem-004 T sensor. Another output of the Molection system is the relay, which controls turning the electrical flow on and off throughout the system in response to commands from the Molection device or the Molection Apps.

C. 3D Design



Fig. 3 Molection 3D design

Fig. 3 shows the manufacturing design result of Molection, which is ergonomically designed for easy installation. Plug it into the socket in the boarding room and connect it to the Wi-Fi network to fully operate with the connected electronic devices.

This design measures 15.814 x 8.593 x 3.651 cm and is printed on a 3D printer using PLA (Polylactic Acid). This material offers a combination of impact resistance and high mechanical strength, making it an ideal choice for products that require durability under physical stress. Furthermore, PLA is heat- and chemical-resistant, making it suitable for use in diverse environments, especially for electrical system covers. The ease of forming and printing PLA also provides flexibility in the manufacturing process, enabling the creation of products with precise details.

This 3D design features four push buttons for reset, switch, down, and select control functions. Additionally, 3 LEDs indicate Wi-Fi connectivity, system status, and relay status, respectively. The design also includes screws for removing and tightening the Molection cover, making maintenance and repair easier. Not only that, there is a socket hole for connecting the electrical load, ensuring easy and safe integration.

D. Interface

Fig. 4 shows the interface design of Molection. This display consists of the main page, which shows the initial view when the Molection application is first

launched. Next is the login menu, used by users who previously received a Molection account; it contains text boxes for entering the user's email address and password.

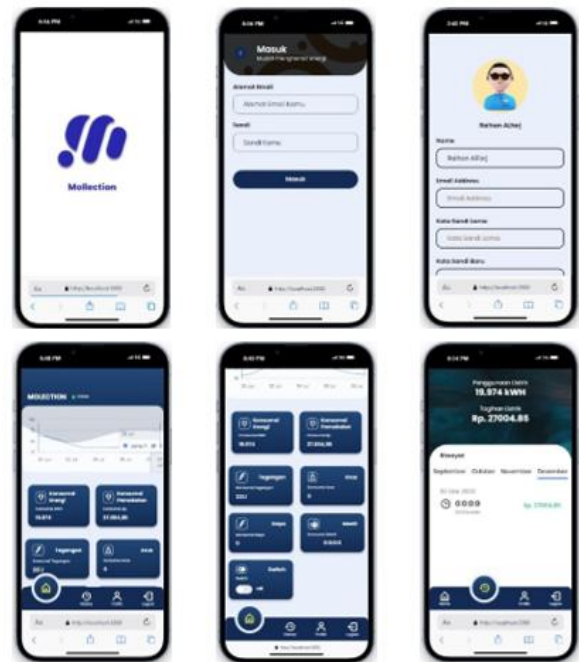


Fig. 4 Molection interface

Next, suppose the user successfully logs in to the Molection application. In that case, the screen will navigate to the main display of Molection, which shows the electrical energy consumption data — voltage, current, and power values in the boarding room — an electricity consumption graph, and the electricity cost to be paid.

At the bottom of the Molection app's main page, there are four menu options: 'Home' for the initial display of Molection measurement data, 'History' menu showing previous electricity consumption history, 'Profile' menu to display the identity of the boarding room occupant and Molection apps user, and 'Exit' menu to log out of the Molection application.

E. Performance Measurement Method of the Design

Design performance is measured by comparing the kWh, current, voltage, and power values of an electronic load measured with electronic measuring instruments to those obtained by Molection. The electronic loads used in the Molection performance measurement use four varying loads with the following details:

1. Load 1: 450 W
2. Load 2: 700 W
3. Load 3: 1150 W
4. Load 4: 2000 W

To determine the accuracy of the energy consumption cost in the system, it is necessary to assess performance by comparing the energy consumption cost value shown in Molection with the cost value obtained from (1).

$$\text{cost} = \text{Kwh} \times \text{energy tariff} \tag{1}$$

With the electricity tariff provisions as stated in the Minister of Energy and Mineral Resources (ESDM) Regulation No. 28 of 2016, with the following conditions:

1. 900 VA: Rp 1,352 per kWh
2. 1300 VA: Rp 1,444.70 per kWh
3. 2200 VA: Rp 1,444.70 per kWh

All measurements related to kWh values and energy consumption costs were conducted for 120 minutes, with values recorded every 15 minutes. To determine the system's accuracy level regarding kWh values and energy consumption costs, calculations of percent error, average percent error, percent accuracy, and average percent accuracy are needed, as shown in (2), (3), (4), and (5).

$$\% \text{ error} = \frac{|\text{Measurement Difference}|}{\text{Measuring Tool Value}} \times 100 \tag{2}$$

$$\% \text{ average error} = \frac{\sum \% \text{ error}}{n} \tag{3}$$

$$\% \text{ accuracy} = 100\% - \% \text{ error} \tag{4}$$

$$\% \text{ average accuracy} = \frac{\sum \% \text{ accuracy}}{n} \tag{5}$$

To support performance measurements, the RMSE (Root Mean Square Error) is also calculated, enabling Molection's performance to be measured more precisely. The RMSE calculation using (6).

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (\text{Measurement Difference})^2}{n}} \tag{6}$$

Furthermore, a performance measurement of the Molection Apps was also conducted by comparing the suitability of the reading values on the Molection device with the values displayed on the Molection Apps

III. RESULT

Table 1 Data from Molection kWh test on a 450 W load

Time (minutes)	kWh (load 450 W)		% accuracy
	Molection	Kwh Meter	
15	0.14	0.15	96.55%
30	0.29	0.29	99.66%
45	0.43	0.43	99.31%
60	0.57	0.58	99.13%
75	0.71	0.72	98.89%
90	0.86	0.86	99.77%
105	1	1.01	99.40%
120	1.15	1.15	99.83%
% average			99.07%
RMSE			0.0046

Table 1 shows the performance data from the kWh measurement conducted with a 450 W load. The Molection system measurement has an average percentage error of 0.93%, an accuracy of 99.07%, and an RMSE of 0.0046.

Table 2. Data from Molection kWh test on 700 W load

Time (minutes)	kWh (load 700 W)		% accuracy
	Molection	Kwh Meter	
15	0.160	0.158	98.73%
30	0.310	0.311	99.68%
45	0.460	0.463	99.35%
60	0.62	0.62	99.35%
75	0.77	0.77	100.00%
90	0.92	0.93	99.46%
105	1.07	1.08	99.53%
120	1.22	1.24	98.63%
% average			99.34%
RMSE			0.0068

Table 3. Data from Molection kWh test on 1150 W load

Time (minutes)	kWh (load 1150 W)		% accuracy
	Molection	Kwh Meter	
15	0.27	0.28	97.83%
30	0.53	0.55	97.07%
45	0.81	0.82	98.78%
60	1.08	1.09	98.81%
75	1.36	1.37	99.34%
90	1.63	1.64	99.21%
105	1.91	1.92	99.53%
120	2.18	2.19	99.41%
% average			98.75%
RMSE			0.0115

IV. DISCUSSION

A. Measurement of Kwh Value of Electronic Load on Molection

Table 4. Data from the Molection kWh test on a 2000 W load

Time (minutes)	kWh (load 700 W)		% accuracy
	Molection	Kwh Meter	
15	0.490	0.481	98.13%
30	0.980	0.960	97.92%
45	1.48	1.44	97.44%
60	1.98	1.93	97.14%
75	2.49	2.42	97.06%
90	2.98	2.89	96.89%
105	3.47	3.37	97.09%
120	3.97	3.86	97.10%
% average			97.35%
RMSE			0.0709

Based on measurements on Molection, performance data for the kWh value was obtained by comparing the measurement values from Molection with the measurement values shown by the wattmeter for four load types, namely 450 W, 700 W, 1150 W, and 2000 W. Referring to the accuracy and error calculations shown in Table 4, Molection has an accuracy percentage of 98.63% with an error percentage of 1.37% in kWh value measurement.

Table 5. Average kWh on Molection

Load	Average	
	% error	% Accuracy
450 W	0.93%	99.07%
700 W	0.66%	99.34%
1150 W	1.25%	98.75%
2000 W	2.65%	97.35%
Molection system average	1.37%	98.63%

However, in Table 5, a phenomenon was observed: an increase in the error percentage and a decrease in the accuracy percentage as the load used approached the maximum load of 2200 W. This phenomenon is caused by the capacity of the Pzem 004-t sensor, which is only capable of measuring a maximum load of 2200 W. Thus, the closer the load value used gets to Molection's maximum load, an increase in the error percentage and a decrease in the accuracy percentage will occur within acceptable limits.

B. Measurement of Load Voltage on Molection

Table 6. Load voltage on Molection

Load	Voltage		% accuracy
	Molection	Voltmeter	
450 W	220.1	219.1	99.54%
700 W	220.1	219.4	99.68%
1150 W	213.9	213.1	99.62%
2000 W	214.9	214.6	99.86%
% average			99.68%
RMSE			0.7450

Table 6 shows the performance data from the voltage measurement, comparing Molection-measured values with those shown by a voltmeter. Based on the measurements taken, the voltage measurement performance on Molection, conducted on loads of 450 W, 700 W, 1150 W, and 2000 W, has an accuracy of 99.68%, an error of 0.32%, and an RMSE of 0.7450. The load voltage measurement error in Table 6 is caused by differences in reading accuracy between the Pzem-004t sensor and the voltmeter. Nevertheless, the existing error percentage is still within an acceptable limit.

C. Measurement of Load Current Value on Molection

Table 7. Data from the load current test on Molection

Load	Current		% Accuracy
	Molection	Amperemeter	
450 W	2.61	2.61	100.00%
700 W	2.81	2.795	99.46%
1150 W	5.14	5.12	99.61%
2000 W	9.03	9.006	99.73%
% average			99.70%
RMSE			0.0173

Table 7 shows the performance data from the current value measurement, obtained by comparing Molection-measured values with those shown by an ammeter. Based on the measurements taken, the performance of the current value measurement on Molection, conducted on loads of 450 W, 700 W, 1150 W, and 2000 W, has an accuracy of 99.70%, an error of

0.30%, and an RMSE of 0.0173. The load current measurement error in Table 7 is caused by differences in reading accuracy between the Pzem-004t sensor and the ammeter. Nevertheless, the existing error percentage is still within an acceptable limit.

D. Measurement of Load Power on Molection

Table 8. Data from the load power test on Molection

Load	Power		% Accuracy
	Molection	Wattmeter	
450 W	576	579.2	99.45%
700 W	603	605.1	99.65%
1150 W	1093.7	1102.8	99.17%
2000 W	1932.7	1956	98.81%
% rata-rata			99.27%
RMSE			12.6526

Table 8 shows the performance data from the power value measurement, obtained by comparing Molection measurements with those from a wattmeter. Based on the measurements taken, the power measurement results on Molection, conducted on loads of 450 W, 700 W, 1150 W, and 2000 W, have an accuracy of 99.27%, an error of 0.73%, and an RMSE of 12.6526. The load power measurement error in Table 5.8 is caused by differences in reading accuracy between the Pzem-004t sensor and the wattmeter. Nevertheless, the existing error percentage is still within an acceptable limit.

E. Test of Electronic Load Cost on Molection

Table 9. Data from the load cost test on Molection

Load	Average	
	% error	% Accuracy
450 W	0.56%	99.44%
700 W	0.59%	99.41%
1150 W	0.79%	99.21%
2000 W	2.85%	97.15%
Average	1.20%	98.80%

Based on the measurement results of Molection's electricity load cost compared to mathematical calculations, as shown in Table 9, Molection has an accuracy rate of 98.80% with an error of 1.20% in measuring the cost of the electronic load. The error in Molection's electricity cost measurement in Table 9 is due to rounding in the cost calculation, which is based on the kWh reading. Meanwhile, Molection's electricity costs are calculated directly within the system. Nevertheless, the existing error percentage is still within an acceptable limit.

The *Molection* system was successfully designed, implemented, and tested to monitor electrical energy consumption in boarding rooms. Testing was conducted to evaluate measurement accuracy, data transmission stability, and user accessibility through the Progressive Web App (PWA).

The implementation of the *Molection* prototype involved assembling hardware components, connecting sensors, and configuring the microcontroller for real-time data transmission. The ESP32 was connected to

the PZEM-004T sensor module to measure voltage, current, power, and energy consumption. The collected data was transmitted via Wi-Fi to the Firebase Realtime Database, which served as the cloud-based storage.

The PWA interface was designed to display measurement data in numerical and graphical formats. The system interface provides users with real-time visualizations of power and energy consumption, daily usage reports, and load status information. Figure 2 shows the user interface of the *Molection* system accessed through a smartphone browser.

System performance testing was conducted by comparing *Molection* sensor readings with reference values obtained from a calibrated digital wattmeter. Table 1 presents the results of the accuracy test for voltage, current, and power measurements.

The results show that the *Molection* system achieved 98.3% measurement accuracy for power and energy readings. The average deviation from the reference measurement was below 2%, which is within the acceptable range for IoT-based monitoring systems. These results indicate that the PZEM-004T sensor and ESP32 microcontroller combination performs reliably for residential energy monitoring applications.

Testing the data transmission process showed that the ESP32 can send sensor data to the cloud database with a latency of less than 1 second under a stable Wi-Fi connection. This demonstrates the system's ability to operate in real time. However, intermittent connectivity may cause short delays in data updates. To mitigate this issue, the firmware includes a data buffering feature to prevent data loss during temporary disconnections.

The PWA-based interface proved effective in ensuring user accessibility and convenience. The app could run seamlessly on multiple devices and browsers without requiring installation. Its responsive design automatically adjusts to various screen sizes, providing consistent performance on mobile and desktop platforms. The integration with Firebase also enables automatic synchronization of data changes, ensuring that all users view up-to-date information simultaneously.

The implementation of *Molection* demonstrates the potential of integrating IoT and PWA technologies for intelligent energy management. Compared to conventional systems, *Molection* offers higher flexibility and accessibility while maintaining reliable performance. The system enables users and administrators to monitor consumption patterns, detect anomalies, and promote energy-saving behavior.

In addition, real-time feedback and visualization features enhance user awareness of energy consumption, supporting sustainable, efficient energy use. This system can be further developed into a scalable monitoring platform for larger facilities, such as dormitories, schools, or office buildings.

F. Impact of System Implementation

The community can feel the impact of the *Molection* System Implementation in 2 main aspects: economic and social. Economically, *Molection* increases the efficiency of electrical energy consumption in boarding rooms. This tool can measure electrical energy consumption, enabling occupants to identify and eliminate energy waste, optimize electricity use in a boarding room, and reduce overall electrical energy consumption costs.

Another aspect that has a significant impact from the use of *Molection* is the social aspect. Implementing *Molection* in boarding rooms will create transparency into electrical energy consumption between boarding house owners and room occupants. Additionally, occupants can independently check the electrical energy they have consumed, fostering awareness of the importance of energy-saving habits. Thus, *Molection*'s convenience and benefits can offer social benefits and create an efficient, transparent environment.

V. CONCLUSION

This study successfully developed *Molection*, an IoT-based system for monitoring electrical energy consumption in boarding rooms, integrated with a Progressive Web App (PWA) interface. The system effectively measures and records voltage, current, power, and energy usage using a PZEM-004T sensor connected to an ESP32 microcontroller.

Testing results indicate that the *Molection* system achieved 98.3% accuracy compared to a standard wattmeter, with data transmission latency of under 1 second in stable Wi-Fi conditions. The web-based PWA interface ensures cross-platform accessibility and provides users with an intuitive visualization of energy consumption patterns in real time.

The application of this system contributes to energy-efficiency efforts by enabling users and administrators to monitor and analyze electricity usage directly on their devices. Future development will focus on improving scalability, integrating predictive analytics for consumption forecasting, and adding remote-control features for automated load management. Overall, *Molection* demonstrates the feasibility and benefits of combining IoT and web technologies to promote energy-conscious behavior and support sustainable management in shared residential environments.

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