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Development of Energy Consumption Measurement and Monitoring System for Household Applications

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Abstract

The existing electricity bill only calculated the monthly usage for the entire house. Because of this, consumers do not know where the electrical energy is being used. This project aims to address these issues by designing a system to monitor the trend of energy consumption of electrical appliances in households with their estimated cost (RM) per month through smartphones. ESP32 is used as the microcontroller of the project, and the PZEM-004T V3 module is utilised to obtain the readings of energy, power, voltage, current, frequency, and power factor of the electrical appliances. The reading can be displayed through Blynk on both desktops and smartphones. The graphical visualisation of the data that has been gathered can also be done with Blynk to ease the process of analysing the trend of energy consumption of electrical appliances in households. As a result, a comparison of energy consumption and estimated cost for different electrical appliances can be done to identify which electrical appliance uses the most energy in the house.

1. Introduction

Efficient use of electricity is important to prevent wasting energy. This is because waste in energy consumption can have effects such as higher electricity bills, higher greenhouse gas emissions, and pollution, which can lead to climate change, respiratory illness, and other health problems. In this case, a system to monitor the energy consumption of electrical appliances in households is necessary so that the trend of energy consumption of the electrical appliances can be analysed, and energy-saving measures can be taken.

Furthermore, the existing electricity bill only calculates the monthly usage for the entire house. Because of this, consumers do not know where the electrical energy is being used. Because of this, consumers do not know where the electrical energy is being used. This project aims to address these issues by designing a system to monitor the trend of energy consumption of electrical appliances in households with their estimated cost (RM) per month through smartphones. This project will primarily focus on residential houses in Malaysia with a single-phase supply (240V 50Hz).

The objectives of this project are to develop a prototype that integrates with the internet of Things (IoT) to monitor the energy consumption of electrical appliances in households with their estimated cost (RM) per month and display the readings on a smartphone. Next, to develop an application to display the readings of energy consumption of electrical appliances through a smartphone. Other than that, to analyse the trend of the energy consumption of the electrical appliances in the household with their estimated cost (RM) per month.

Table 1 shows the summary of the comparison of previous projects that are related to the objectives of this project. There are different types of microcontrollers used, such as the Arduino Uno and the ESP8266. Meanwhile, the sensors used to monitor the electricity energy are an ACS172 current sensor and a PZEM-004T sensor module. The useful input from previous projects will be used to improve the author's project.

Table 1 *Comparison of the previous project*

Title of project	Description	Methods
Energy Monitoring for Household Electrical Devices [1]	Energy monitoring systems integrate with the IoT, focusing on electrical devices in households.	-Blynk as IoT platform. -Wemos D1R1 as microcontroller. -ACS172 current sensor. -PLX-DAQ was used for data logging in Microsoft Excel for analysis.
A Smart Home Energy Consumption Monitoring System Integrated with Internet Connection [2]	A web-based, real-time electricity energy consumption monitoring system for residential usage.	-ESP8266 as the microcontroller. -PZEM-004T is used to read power consumption and current. -A web-based application was developed using a Sublime Text 3 text editor.
Design of Raspberry Pi Web-based Energy Monitoring System for Residential Electricity Consumption [3]	The electrical energy monitoring system uses the PZEM-004T module and the Raspberry Pi 4 as a web server.	-PZEM-004T module as the sensor of the project. -Raspberry Pi 4 as the web server.
Electricity Power Monitoring Based on the Internet of Things [4]	Energy monitoring tool system with a historical graph of power	-PZEM-004T as the sensor of the project. -Arduino Uno as the microcontroller. -Uitlised Wemos D1 Mini Wi-Fi module. - Blynk to display readings.
IoT-Based Customer kWh Meter Design [5]	IoT-based kwh meter monitoring tool to monitor kW, energy (kWh), voltage, and current consumption by household electrical equipment.	-NodeMCU as microcontroller. -PZEM-004T as the sensor of the project. -A digital MCB -Sockets for the load to be plugged in

2. Materials and Methods

2.1 Materials

The materials needed to develop the prototype of the project are divided into two parts: hardware development and application development.

The materials needed for hardware development are:

i. Main Switch
ii. Residual Current Circuit Breaker (RCCB)
iii. Miniature Circuit Breaker (MCB)
iv. ESP32 is the microcontroller for the project.
v. Module Sensor PZEM-004T V3 is used to measure AC voltage, current, active power, frequency, power factor, and active power.

On the other hand, the materials needed for the application development are:

i. Arduino IDE is used to program the coding of the system.
ii. Blynk for the display of the readings that can be accessed by smartphone or desktop computer.

2.2 Methods

The methods in developing the prototype of the project include a block diagram of the system, a flowchart of the system, and a circuit design of the hardware. Figure 1 shows the block diagram of the system. At the input, an AC/DC adapter is used as a power supply for the ESP32. The main supply of 240V AC from the distribution board (DB) is supplying power for the load, and the neutral wire from DB to the switch socket is being clamped by the current transformer (CT) from PZEM-004T V3 to measure current. In addition, live and neutral wires of switch sockets need to be connected to the module for the measurement of voltage, power, energy, frequency, and power factor. The data from the module will then be transferred to ESP32 during the process part of the block diagram. This is to allow data from the sensor to be sent to the Blynk application through the wi-fi module of the ESP32. Then, the value of energy, power, voltage, current, frequency, and power factor will be displayed on the Blynk application to enable analysis to be carried out.

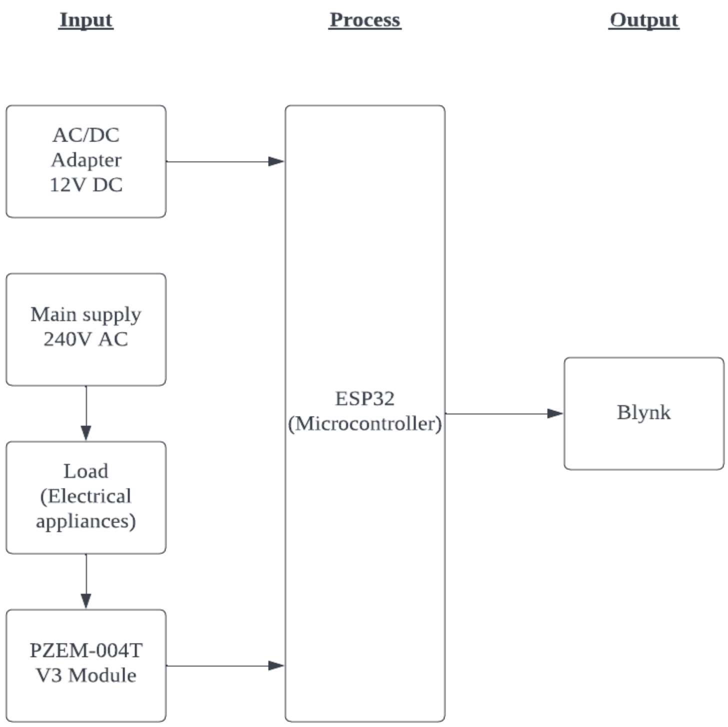


Fig. 1 *Block diagram of the system*

Figure 2 shows the flowchart of the system. The system starts with 240V AC being supplied to the switch socket and an AC/DC adapter supplying 5V DC power to the ESP32. When the switch socket with a load, which is an electrical appliance, is switched on, the PZEM-004T V3 Module will start measuring the value of energy, power, voltage, current, frequency, and power factor of the electrical appliance. The data will then be transmitted to ESP32 to be processed. Based on the data from the PZEM-004T module, ESP32 will compute the estimated cost (RM) per month for energy. After that, the data is transmitted to Blynk using the wi-fi module of the ESP32 and can be displayed on the Blynk application through a smartphone or web dashboard. If the reset button on the Blynk application is pressed, the energy (kWh) and estimate cost (RM) per month reading will be reset to 0, and the measurement process will continue. Otherwise, if the reset button is not pressed, the process will repeat continuously, and the reading of energy consumption (kWh) will keep adding up. The system ends when the power supply is disconnected.

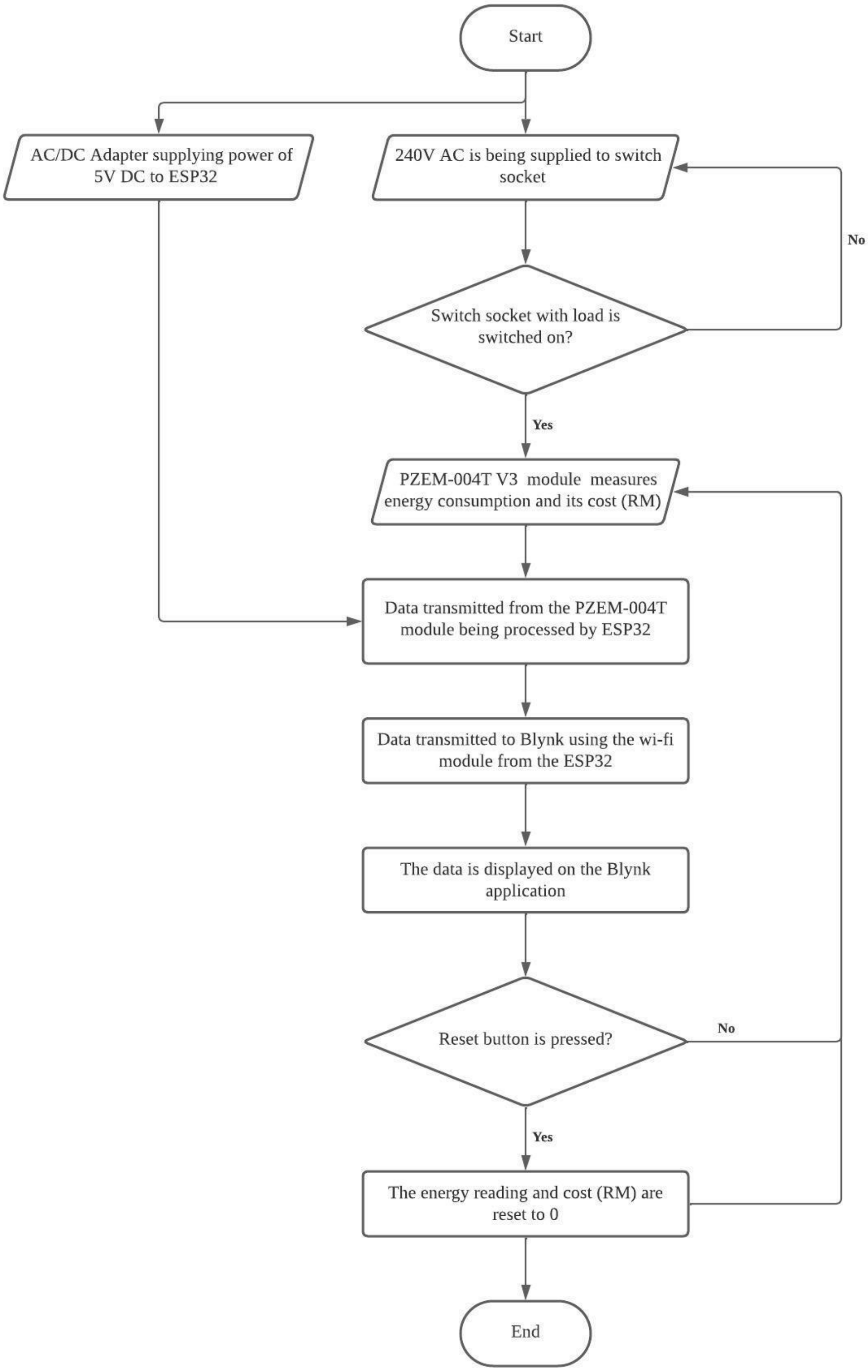


Fig. 2 *Flowchart of the system*

Figure 3 shows the circuit design of the hardware. Firstly, 240V AC is supplied to the distribution board. Then, MCB C20 is connected to the switch socket, which will be used as the load in this system when the socket is being plugged in by electrical appliances. Meanwhile, ESP32 is getting a supply of 5V DC to operate. From the ESP32, the Vin pin and GND pin are connected to the 5V and GND pins of the PZEM-004T sensor, respectively. Then, the RX pin from ESP32 is connected to the TX pin on PZEM-004T to receive serial data from PZEM-004T, and the TX pin from ESP32 is connected to the RX pin on PZEM-004T to transmit serial data to PZEM-004T. Furthermore, the split-core current transformer of the PZEM-004T module needs to be clamped around a live or neutral wire to measure current. The live and neutral wires from the load also need to be connected to the PZEM-004T V3.

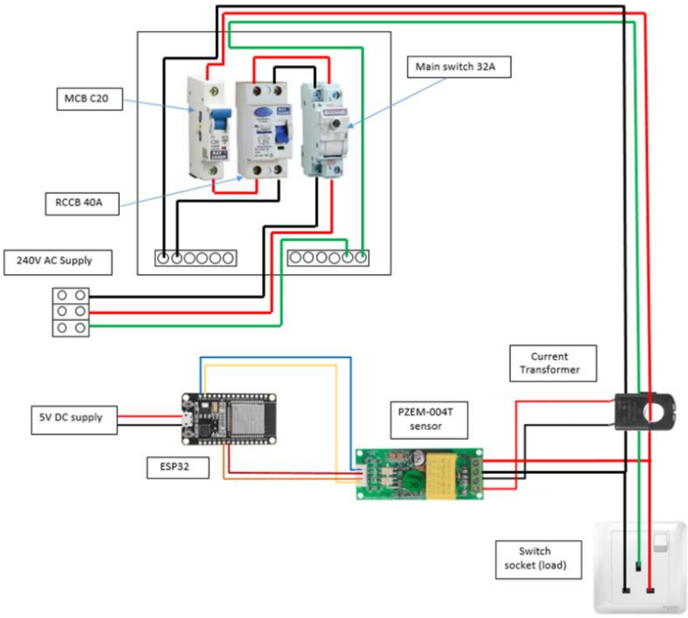


Fig. 3 *Circuit design of the hardware*

The development method of the project has been presented to ensure the project runs smoothly. The block diagram provides an overview of the project structure by outlining the main components and the interactions between them. The flowchart of the system depicts a detailed sequence of steps and decision points involved in the operation of the project. Circuit design, on the other hand, provides an overview of the arrangement of components for the circuit of the hardware.

3. Result and Discussion

3.1 Project Prototype

Figure 4 shows the final design of the prototype and circuit connection inside the enclosure box. The wiring and circuit connection of the prototype is based on the circuit design in Figure 3. The wiring details are close to PVC trunking.

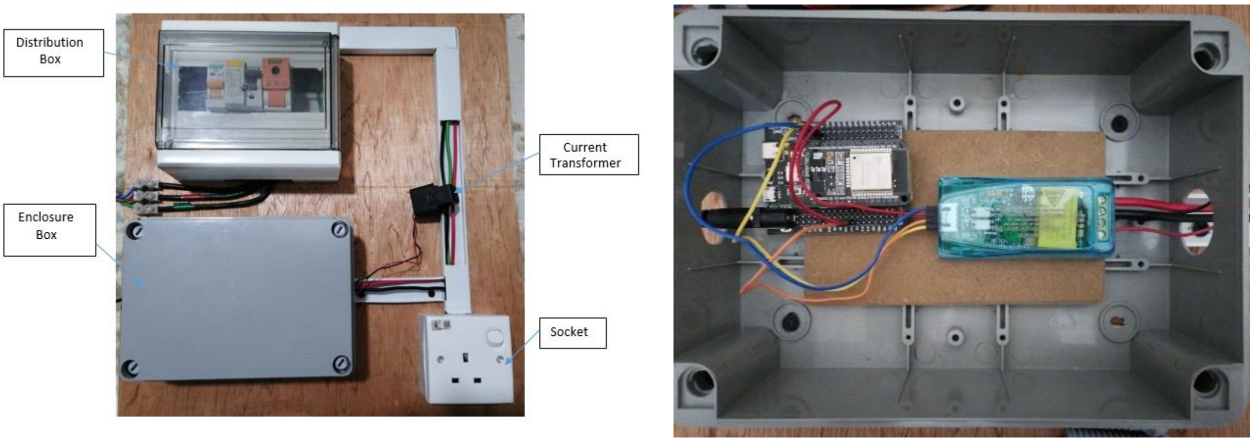
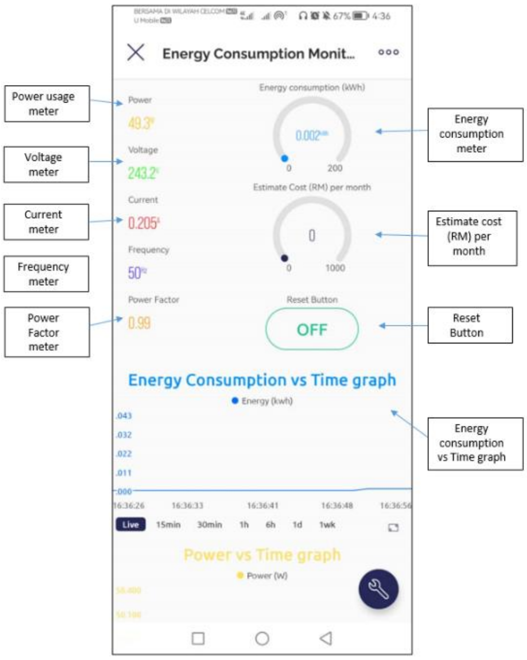


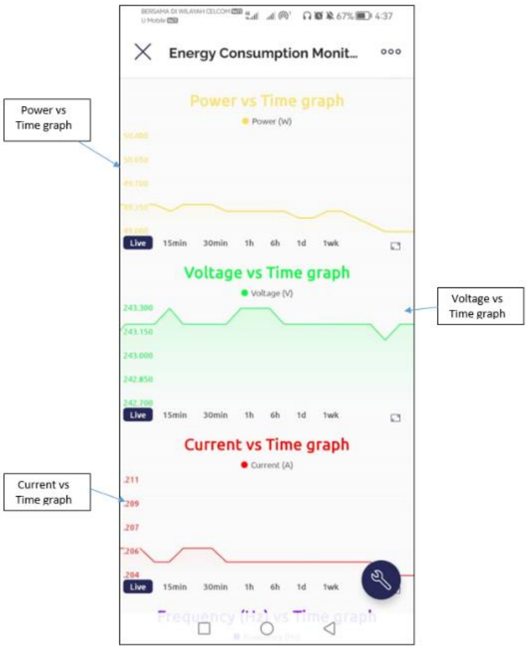
Fig. 4 *Final design of the prototype and circuit connection inside the enclosure box*

3.2 Blynk Application Interface

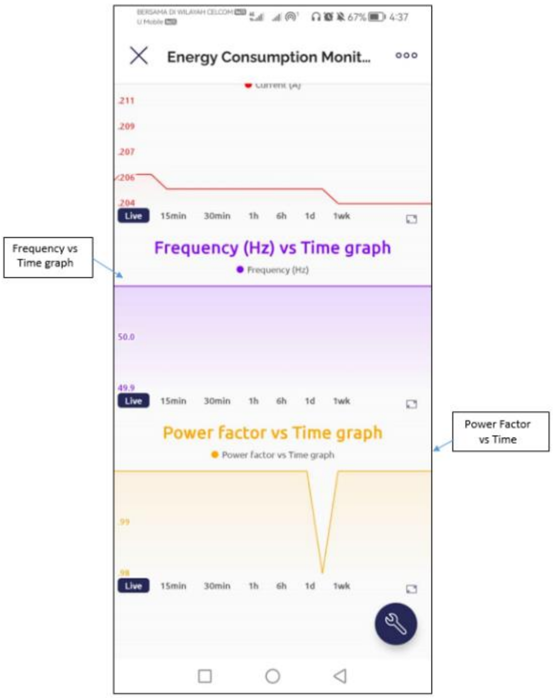
The interface of the Blynk application for the prototype is shown in Figure 5 (a), (b) and (c). The Blynk application can be accessed through a smartphone, and it is scrollable to show the full interface. In Figure 5 (a), at the left, there is a power usage meter, a voltage meter, a current meter, a frequency meter, and a power factor meter. The widget used for these meters is a display value type. On the right, there is an energy consumption meter, an estimated cost (RM) per month meter, and a reset button. The widget used for the energy consumption meter and estimated cost (RM) per month meter is a gauge type. Below, there are parameter vs time graphs, starting with the energy consumption vs time graph.



(a)



(b)



(c)

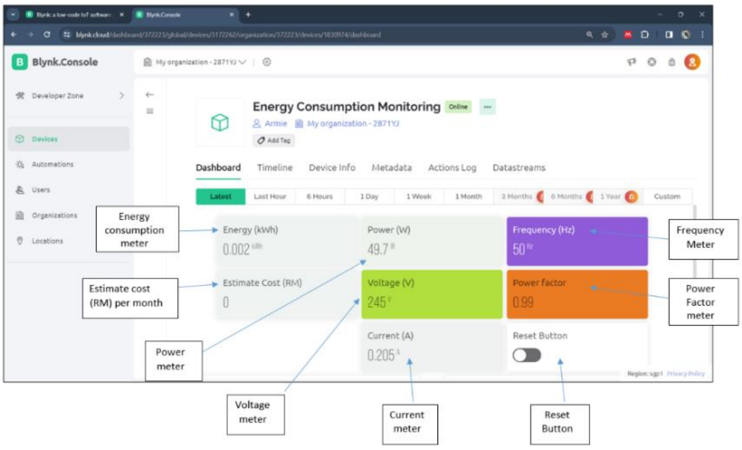
Fig. 5 *Blynk Application Interface (a) Upper portion, (b) Middle portion, (c) Lower portion*

3.3 Blynk Dashboard Interface

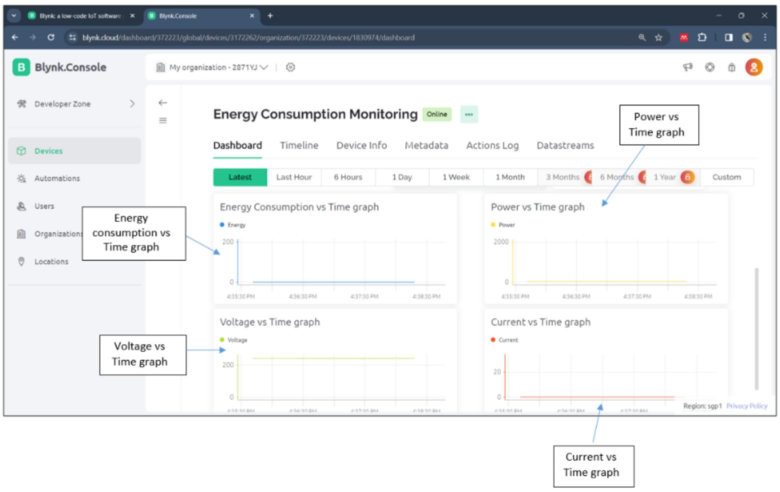
The readings from the prototype can also be viewed on the desktop through the Blynk Dashboard. The data that is displayed on the Blynk Dashboard is the same as that shown in the Blynk application. The interface of the Blynk dashboard for the prototype is shown in Figure 6. The Blynk dashboard can be accessed on the Blynk website through a desktop computer, and this dashboard is scrollable to show the full interface. As shown in Figure 6 (a), there is an energy consumption meter, an estimated cost (RM) per month meter, a power meter, a voltage meter, a current meter, a frequency meter, a power factor meter, and a reset button. The widget used for the meters is a labelled type, while the reset button is a switch type.

Then there is the energy consumption vs. time graph, power vs. time graph, voltage vs. time graph, and current vs. time graph, as shown in Figure 6 (b).

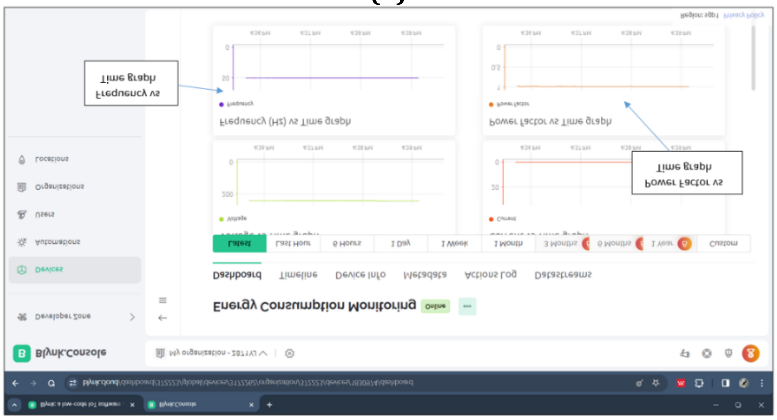
Furthermore, there is a frequency vs time graph and a power factor time graph, as shown in Figure 6 (c). The widgets used for all the graphs are of the chart type. All these graphs are based on real-time readings, and the values are the same as the values on the meters in Figure 6 (a).



(a)



(b)



(c)

Fig. 6 *Blynk Application Interface (a) Upper portion, (b) Middle portion, (c) Lower portion*

In addition, from the Blynk Dashboard, a report can be generated in CSV format as shown in Figure 7. The data for the report can be from the last 24 hours, weeks, or months. The aggregation of the data can be from 1 minute, 1 hour, or one day. The data in the report is averaged over 1-minute intervals. From this report, the analysis process can be much easier.

	A	B	C	D	E	F	G	H	I
1	Time	Power	Energy	Voltage	Current	Frequency	Power fac	Reset Button	RM
2	12/25/23 05:02:00 PM	0	0.003	244.4	0.036	50	0		0
3	12/25/23 05:01:00 PM	0	0.003	244.3829	0.036	50	0		0
4	12/25/23 05:00:00 PM	0	0.003	244.2951	0.036	50	0		0
5	12/25/23 04:59:00 PM	0	0.003	244.161	0.036	50	0		0
6	12/25/23 04:58:00 PM	0	0.003	243.4825	0.036025	50	0		0
7	12/25/23 04:57:00 PM	0	0.003	243.4098	0.036	50	0		0
8	12/25/23 04:56:00 PM	0	0.003	241.5293	0.035951	50	0		0
9	12/25/23 04:55:00 PM	0	0.003	243.8195	0.036	50	0		0
10	12/25/23 04:54:00 PM	0	0.003	244.1075	0.036	49.9878	0		0

Fig. 7 *Generated report from Blynk in CSV format*

3.4 Trend of Energy Consumption of The Electrical Appliances

In this section, the goal is to analyse the trend of energy consumption for different electrical appliances in households, including their estimated cost (RM) per month for 30 minutes. The electrical appliances that are being tested are a table fan, LED lamp, vacuum, air purifier, and iron. The theory behind the calculation of the estimated cost (RM) per month is as follows:

$$Estimate\ cost\ (RM) per\ month = Energy\ consumption\ (kWh)\ \times RM0.218 \quad Eq.1$$

This is based on the domestic tariff from TNB [6]. For the first 200 kWh per month, the rate is RM0.218.

3.4.1 Table fan

The prototype has been tested on a table fan with 55W at the highest speed. The result for table fan 55W is shown in Figure 8. The energy consumption of a 55W table fan for 30 minutes is 0.02434 kWh, with an estimated cost (RM) per month of RM0.0053. From the graph, it shows that the readings of the energy consumption of the 55W table fan are increasing steadily every minute.

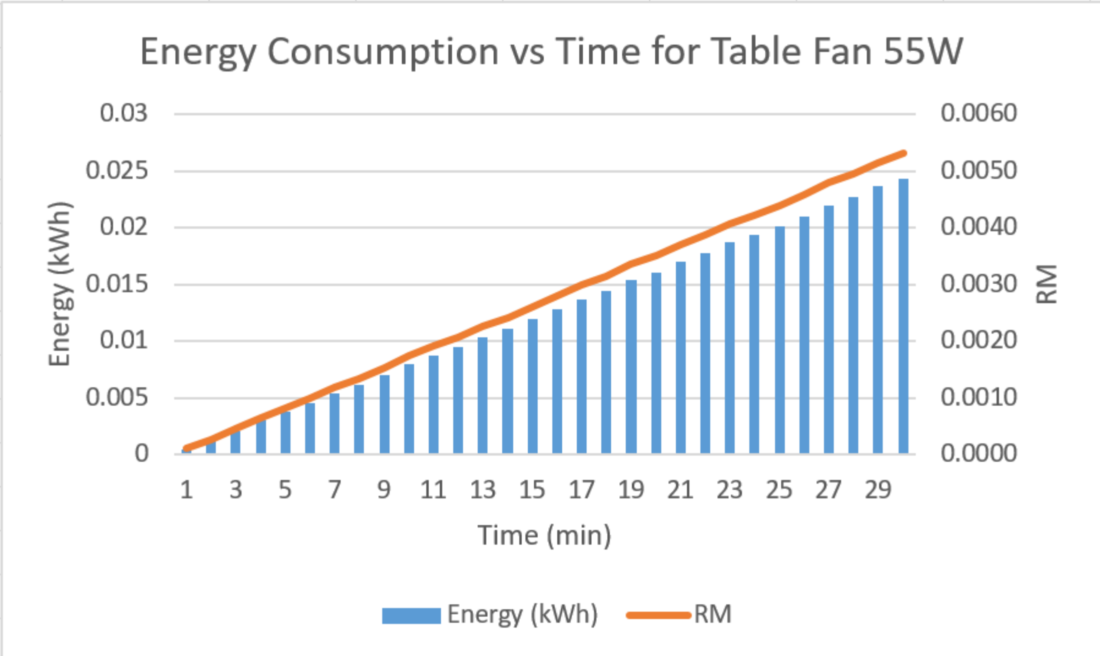


Fig. 8 *The result for table fan 55W.*

3.4.2 LED lamp

The prototype has been tested on an LED lamp with 9W. The result for LED lamp 9W is shown in Figure 9. The energy consumption of an LED lamp of 9W for 30 minutes is 0.004 kWh, with an estimated cost (RM) per month of RM0.0009. From the graph, it shows that the energy consumption of LED 9W increased gradually. The energy consumption readings remain constant for 6 to 7 minutes before continuing to increase.

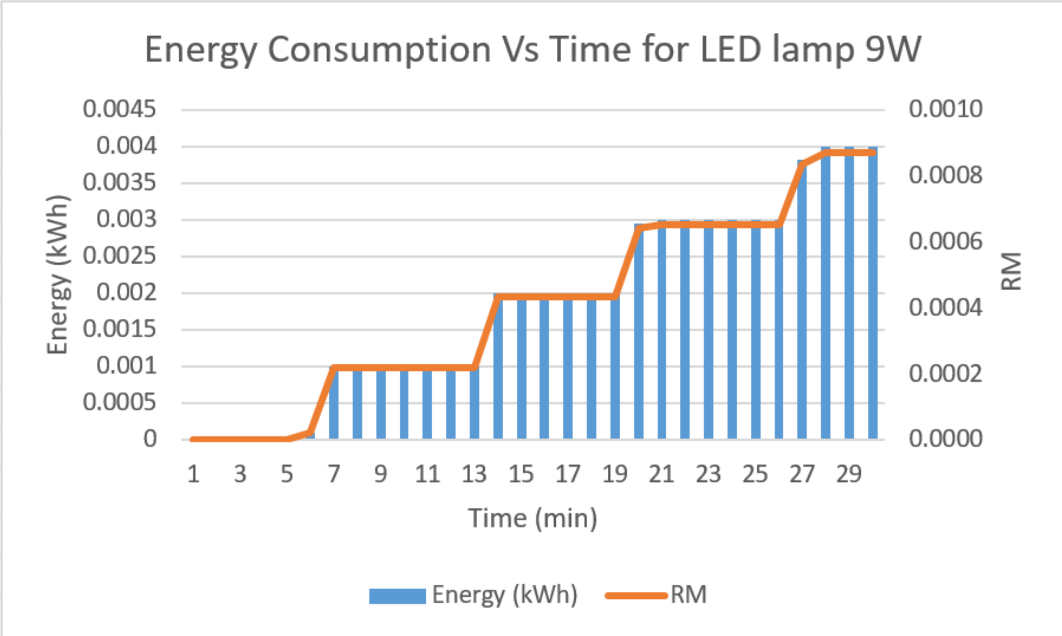


Fig. 9 *The result for LED lamp 9W.*

3.4.3 Vacuum

The prototype has been tested on a vacuum with 850W. The result for vacuum 850W is shown in Figure 10. The energy consumption of a vacuum 850W for 30 minutes is 0.3859 kWh, with an estimated cost (RM) per month of RM0.0841. From the graph, it shows that the readings of the energy consumption of the vacuum 850W are increasing significantly every minute.

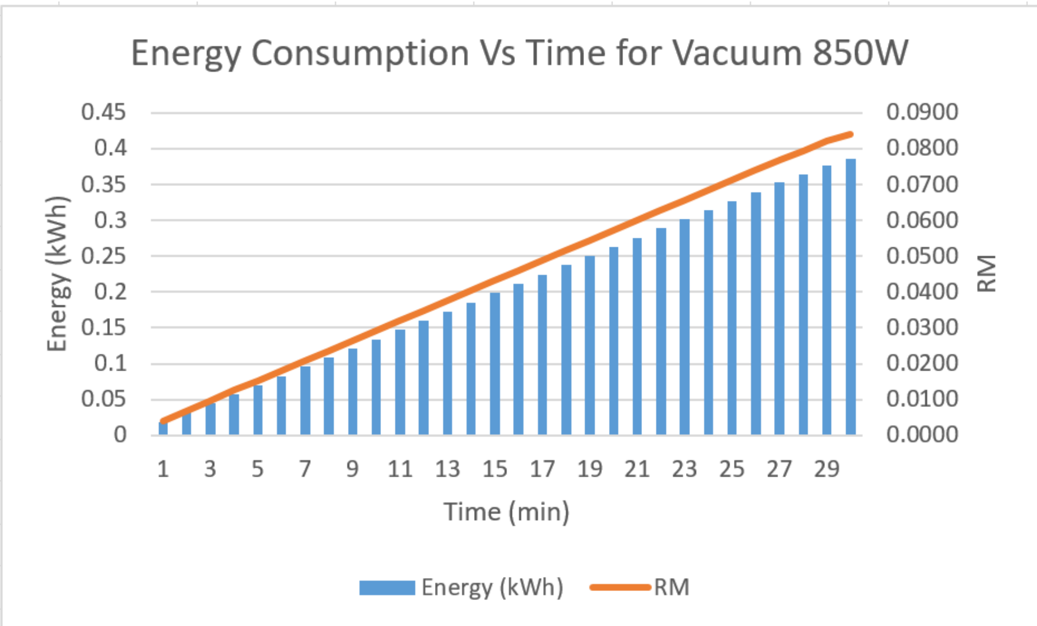


Fig. 10 *The result for vacuum 850W.*

3.4.4 Air Purifier

The prototype has been tested on an air purifier with 33W. During the test, the air purifier purifies the air automatically based on the air conditions. The worse the condition of the air, the more energy it takes to purify it. The result for the air purifier 33W is shown in Figure 11. The energy consumption of an air purifier of 33W for 30 minutes is 0.004 kWh with an estimated cost (RM) per month of RM0.0009. From the graph, it shows that the readings of the energy consumption of the air purifier are increasing moderately.

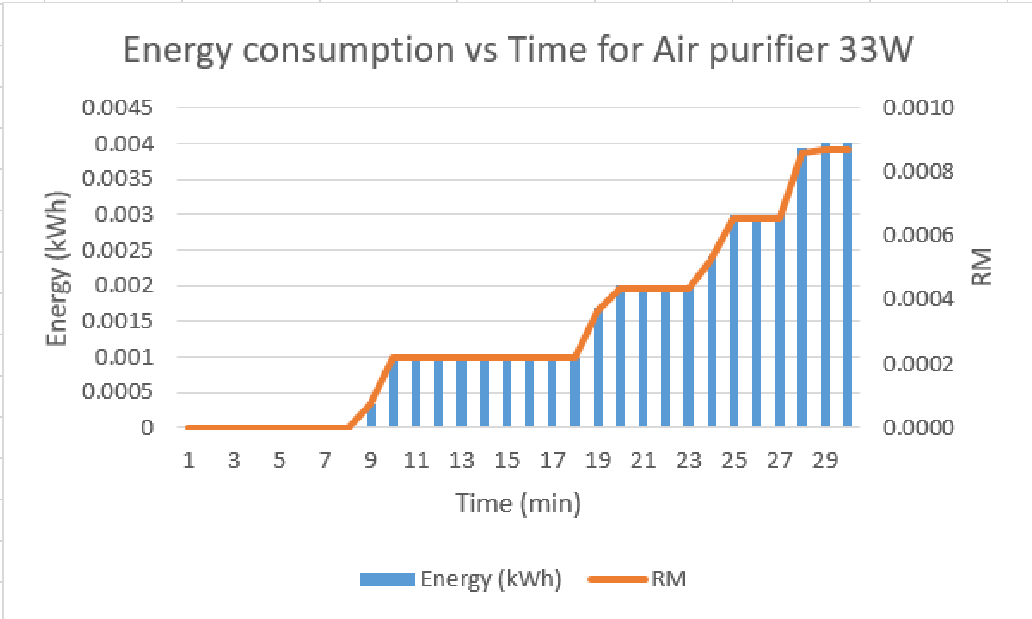


Fig. 11 *The result for Air Purifier 33W.*

3.4.5 Iron

The prototype is being tested on Iron with 1000W on a cotton setting. The result for iron 1000W is shown in Figure 12. The energy consumption of iron 1000W for 30 minutes is 0.1133 kWh, with an estimated cost (RM) per month of RM0.0247. The graph shows that the readings of the energy consumption of iron 1000W are increasing considerably.

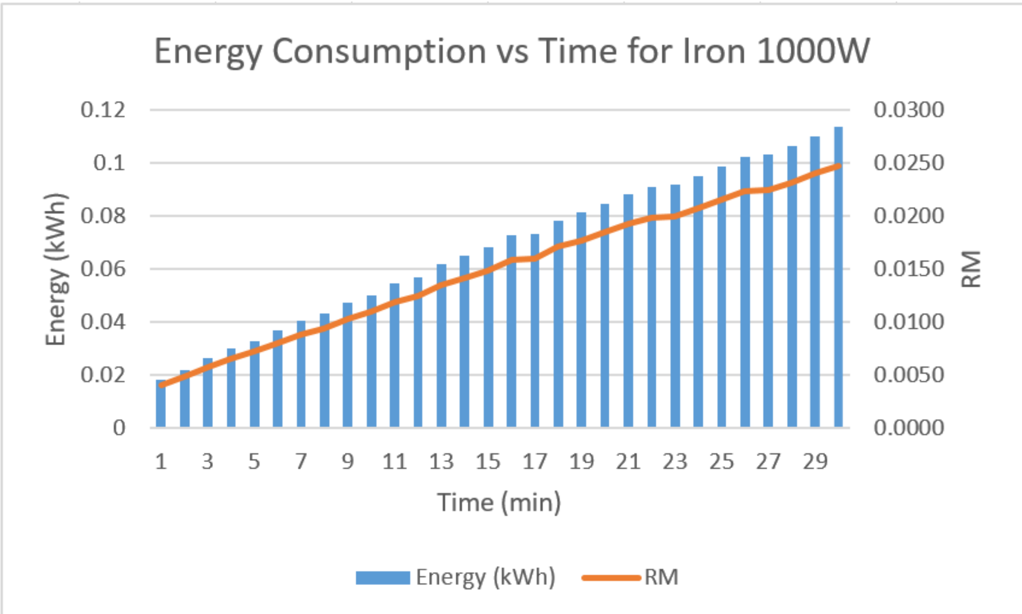


Fig. 12 *The result for Iron 1000W.*

3.4.6 Electrical Appliances Energy Consumption Comparison

Figure 13 shows the energy consumption of different electrical appliances for 30 minutes and the estimated cost (RM) per month. The data in the figure is based on previous testing. The total energy consumption of all these electrical appliances is 0.5315 kWh, with an estimated cost of RM0.1159.

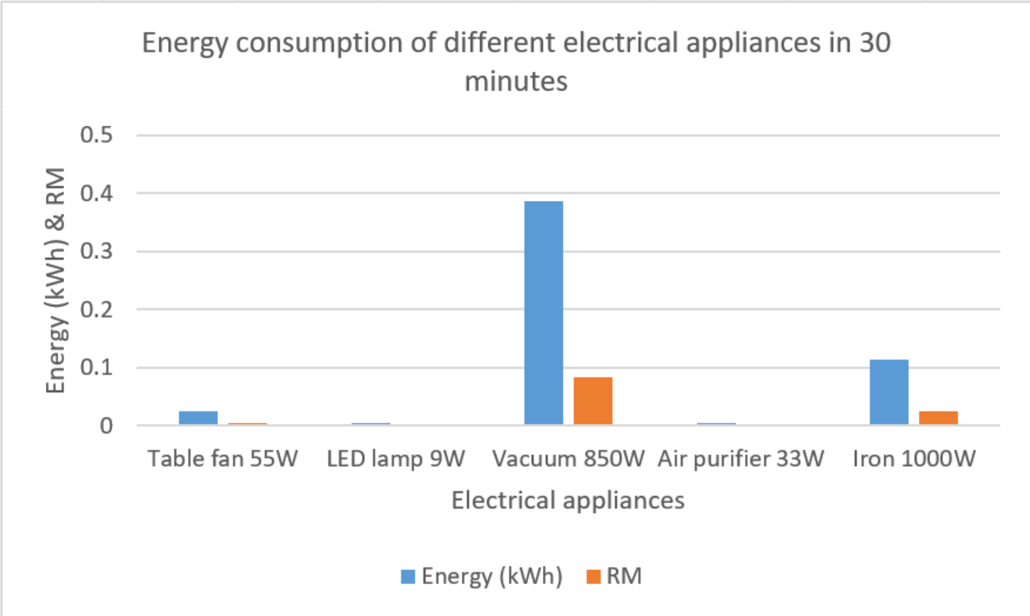


Fig. 13 *Electrical appliances energy consumption comparison.*

Based on the figure, it shows that the electrical appliance with the highest energy consumption (kWh) in 30 minutes is vacuum 850W, which is 0.3859kWh with an estimated cost (RM) per month of RM0.0841. Followed by iron 1000W with 0.11327kWh and an estimated cost of RM0.0247 and table fan with 0.0242kWh and an estimated cost of RM0.0053. Meanwhile, LED lamp and air purifiers have the same readings for energy consumption and estimated cost per month, which is 0.004kWh and RM0.0009, respectively. Vacuum 850W consumes more energy in 30 minutes compared to iron 1000W because iron has a built-in thermostat to regulate the temperature of the iron's soleplate. This thermostat will open the circuit when the iron reaches the desired temperature based on the setting on the iron and will close the circuit when the temperature drops [7]. This means that iron does not function for the full 30 minutes during the testing as there is a time when iron will open the circuit when the temperature reaches a certain limit, and this is not the case with a vacuum.

4. Conclusion

In conclusion, the "Development of Energy Consumption Measurement and Monitoring System for Household Applications" project has been completed. This project has been proven to be able to monitor the energy consumption of electrical appliances and their estimated cost (RM) per month in households through a smartphone. In this case, from this project users can identify areas where a lot of energy is used and can take saving measures. However, there may be a slight error on Blynk and the practical measures because the data in the generated report averages data over 1-minute intervals.

Acknowledgement

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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