PROTOTYPE DESIGN AND DEVELOPMENT OF AN IOT-BASED ELECTRONIC DEVICE MONITORING AND CONTROL SYSTEM AT BAITUL MARIFAH MOSQUE POLTEKBANG SURABAYA USING A WEBSITE INTERFACE

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ABSTRACT
Electrical energy usage in mosques is often inefficiently controlled due to the lack of an integrated automatic monitoring and control system. This results in power wastage and difficulty in managing electronic devices that operate for long periods of time. To address these issues, this study aims to design and build an Internet of Things (IoT)-based electronic device monitoring and control system that is integrated with a website interface and can be accessed in real time. This system is designed to support the implementation of the smart mosque concept through energy efficiency and electricity management automation. The study uses a 4D (Define, Design, Develop, Disseminate) R&D model approach, by integrating an ESP32 microcontroller, a PZEM-004T sensor to measure electrical parameters (Voltage, current, power, and energy), and Firebase as a cloud-based data communication platform. Testing is carried out by assessing the validator to transmit data readings and device control stability via the website. The results show that the system is able to provide current, Voltage, and power data readings in accordance with field data compared to standard measuring instruments in the form of a Clampmeter and performs control functions responsively and stably. This research provides a practical contribution in the development of a cost-effective and easy-to-implement system for digitalizing energy management in mosques, as well as being the first step towards implementing IoT-based micro-scale smart building technology .

Keywords: *IoT, energy monitoring, Firebase, ESP32, R&D*

INTRODUCTION

Efficient and transparent electricity management is an urgent need in the digital era. Ideally, an electricity consumption monitoring system is integrated with web-based technology, allowing users to access *real-time power usage information* anytime and anywhere. With the support of an automated, measurable system connected to a digital platform, energy management can be carried out more efficiently, controlled, and planned [1]. One technology that can answer these needs is the Internet of Things (IoT), because it is able to measure electrical parameters accurately while supporting remote control of electronic devices [2], [3]. The implementation of this technology is very relevant for application in environments that operate routinely and continuously, such as mosques [4].

The current situation at the Baitul Marifah Mosque demonstrates a gap between ideal needs and reality. Electricity management is still carried out manually, with devices such as lights, fans, and other electronic equipment operated without an adequate control system. The lack of a mechanism for recording and analyzing electricity consumption data makes it difficult for mosque administrators to monitor overall energy usage patterns. This has implications for unnoticed energy waste and increased monthly electricity costs [5]. Therefore, a technology-based solution is needed that can provide a *real-time energy consumption monitoring and control system* .

The solution offered in this research is the development of a prototype IoT device for monitoring and controlling electricity consumption. This system not only provides *real-time power information* , but also calculates estimated electricity costs based on energy consumption data [6]. Another advantage of this prototype is its innovative, more flexible design, where electronic components are protected with a lamp cap instead of a conventional *casing* . With the support of the PZEM-004T module for reading electrical parameters, as well as an ESP32 microcontroller connected to a Wi-Fi network, the device can be accessed through a website-based interface using Firebase [7].

Based on this background, this research is focused on answering several questions, namely: how to design a prototype system for power consumption and *real-time electrical load control* based on IoT; how the system can calculate electrical energy based on consumption data and tariffs per kWh; how the system's accuracy level compares to standard measuring instruments such as ampere clamps; and how the system's feasibility level is based on media expert assessments.

The main objective of this research is to design and develop an innovative IoT-based system capable of monitoring power consumption and controlling electrical loads in *real time* . Furthermore, this research also aims to develop an electricity cost estimation calculation feature so that users obtain clear information regarding energy saving opportunities [8]. It is hoped that this system can increase user awareness of energy efficiency and support more informed decision-making in managing electricity consumption.

The research results are expected to provide both practical and academic benefits. For mosque administrators, this system can be a solution to reduce energy waste and reduce operational electricity costs. For the general public, this system can be used as a reference in adopting IoT technology for energy monitoring in households and other public facilities [9]. Thus, this research not only contributes to energy efficiency but also serves as an initial step towards implementing the concept of a modern, energy-efficient, and adaptable *smart mosque* to the development of digital technology.

RESEARCH METHODS

Types of research

In this final project, the research method used is Research and Development (R&D) with the Four D (4D) model approach. This model was developed by Thiagarajan, Semmel, and Semmel in 1974, which consists of four main stages: *Define* , *Design* , *Develop* , and *Disseminate* [10]. The 4D model is widely adopted in research aimed at creating new products that are applicable, effective, and can be widely used by the community [11].

In this research, the product developed is an Internet of Things (IoT)-based electronic device monitoring and control system implemented at the Baitul Marifah Mosque. This system is expected to help mosque administrators monitor electricity consumption in real time and control electronic devices remotely via a website.

4D Model Stages

Each stage in the 4D model has interrelated functions and outcomes. The *Define stage* aims to formulate actual needs and problems in the field, the *Design stage* is used to design a technical system according to needs, the *Develop stage* is to implement and test a system prototype, and the *Disseminate stage* is to distribute and evaluate the system by involving expert validators [12].

This approach was chosen because it is relevant in the context of IoT-based technology development, particularly for monitoring and controlling the use of electrical energy efficiently and in real time in places of worship.

Research Flow

The detailed research stages are as follows:

1. **Start – Project Initiation**

The determination of this research topic comes from observations at the Baitul Marifah Mosque, Poltekbang Surabaya, which manages electrical energy manually, causing power wastage in 8 AC units (7 Ampere/unit) and increasing operational costs, thus giving rise to the topic "Design and Construction of a Prototype Monitoring and Control System for IoT-Based Electronic Devices Using a Website" with a 4D R&D approach.

The goal is to design an IoT system using ESP32, PZEM-004T sensor, relay module, and Firebase for real-time power monitoring and control, calculate electricity costs based on PLN tariffs (Rp1,444.70/kWh, R-1 2,200 VA, Quarter 1 2025), and evaluate accuracy with a clampmeter through the formula:

Percentage error , namely *:*

$$Error\ (\%) = \frac{\text{DataPZEM} - \text{DataClamp}}{\text{DataClamp}} \times 100\%$$

Then, accuracy is obtained from:

$$\text{Accuracy } (\%) = 100\% - \text{Error } (\%)$$

Then, the deviation is obtained from:

$$\text{Deviation} = (\text{Error} - \text{Average Error})$$

As well as assessing the feasibility via a Likert scale, with the limitation of a prototype without a mobile application or industry certification, to digitize mosque energy management and support the concept of a micro-scale smart building.

Problem identification highlights the lack of an automated monitoring and control system, leading to difficulties in comprehensively monitoring energy consumption and power wastage.

So there are 4 problem formulations covering

1. How to design an IoT system for real-time monitoring and control,
2. Calculating electricity costs,
3. Evaluate the accuracy of the system compared to a clampmeter,
4. Assess the feasibility of the system based on expert judgment.

2. Tool Design

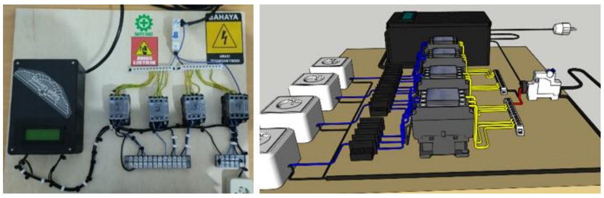

Figure 1. Design Plan
Source: Author's Processing (2025)

In Figure 1. above, it is explained that the design begins with the creation of a design that integrates the PZEM-004T sensor to measure electrical parameters (voltage, current, power, energy), the NodeMCU ESP32 microcontroller as a data processing center with WiFi connectivity, a 4-channel 5V relay module for device control, and the Firebase server as a cloud platform for storing and managing data in real time. The data flow is designed linearly: the PZEM-004T sensor collects electrical data from devices such as 8 AC units (7 Ampere/unit) at the Baitul Marifah Mosque, the data is processed by the ESP32, sent to Firebase via WiFi, then displayed and controlled by the user through the website interface.

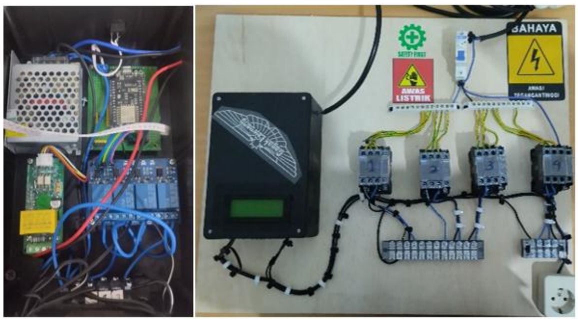

Figure 2. Network Design
Source: Author's Processing (2025)

In Figure 2. above it is explained that the electronic circuit design includes detailed connections between the PZEM-004T sensor (with Current Transformer/CT), ESP32, relay, and 5V 3A power supply module to ensure stable operation, with a visualized wiring scheme to meet electrical safety standards. With hardware specifications including: PZEM-004T (accuracy ±1%, measuring up to 100A), ESP32 Devkit V1 (32-bit, WiFi-enabled), 5V 4-channel optocoupler relay (capacity 10A/250VAC), 5V 3A power supply, CT cable (capacity according to load), and PCB for integration.

3. Tool Making

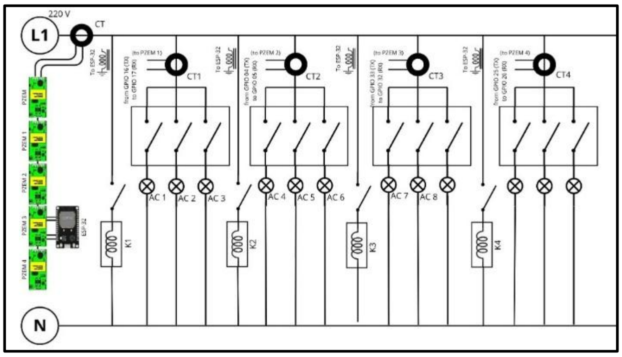

Figure 3. SIMPLE Block Diagram
Source: Author's Processing (2025)

In Figure 3. above, it is explained that the creation of the tool in this project begins with assembling the hardware according to the block diagram and schematic, integrating the PZEM-004T sensor to measure electrical parameters (voltage, current, power, energy) from 8 AC units (7 Ampere/unit) at the Baitul Marifah Mosque, the NodeMCU ESP32 microcontroller for data processing, a 5V 4-channel optocoupler relay module for control, and a 5V 3A power supply for stable operation, with connections on the PCB and CT cables according to electrical safety standards.

In this project, the ESP32 is programmed using the Arduino IDE. The ESP32 is used to send data to the Firebase Realtime Database. Below, the researcher will explain the setup and code required to connect the ESP32 to Firebase and how to read data from the sensors.

WiFi Configuration:

```
// WiFi Configuration
#define WIFI_SSID "IndiHome"
#define WIFI_PASSWORD "1 to 8"
```

Set up a Wi-Fi router with the appropriate SSID and password to allow the device to connect to the internet. Next, configure Firebase:

```
// Firebase Configuration
#define FIREBASE_HOST "https://monitoringdaya-8675a
default-rtdb.firebaseio.com"
#define FIREBASE_AUTH "AIzaSyAyfuMk
AIo2r2geuzOHI3oVvCTa7RM7q0"
FirebaseData fbData;
FirebaseAuth
FirebaseConfig config;
```

Firebase is configured using a host and authentication token, so that the device can connect to the Firebase database.

PZEM004T (Power Meter Sensor) Settings:

```
// Object PZEM004T (Use appropriate GPIO)
PZEM004Tv30 pzem(Serial2, 16, 17); // RX = 16, TX =
17
```

The PZEM004T sensor measures power, voltage, and current, which can then be read by the ESP32. The ESP32's GPIO connections have been precisely mapped to their corresponding pins.

The ESP32's Setup function plays a crucial role in initial device configuration, such as connecting to a Wi-Fi network and initiating a connection with Firebase. Here's a more in-depth explanation of the setup code:

```
void setup() {
Serial.begin(115200);
WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
Serial.print("Connecting to WiFi...");
while (WiFi.status() != WL_CONNECTED) {
delay(1000);
Serial.print(".");
}
Serial.println("Connected!");

config.host = FIREBASE_HOST;
config.signer.tokens.legacy_token =
FIREBASE_AUTH;
Firebase.begin(&config, &auth);
}
```

In this function, the ESP32 will first attempt to connect to Wi-Fi using the configured SSID and password. If the connection is successful, the ESP32 will proceed to initialize the connection to Firebase to begin sending data.

configuration for web applications can be done by integrating the Firebase SDK. Here is an example of a Firebase configuration that can be used for a web application:

```
const firebaseConfig = {
apiKey: "AIzaSyD*",
authDomain: "projectname.firebaseapp.com",
databaseURL: "https://projekname.firebaseio.com",
projectId: "projectname",
storageBucket: "projekname.appspot.com",
messagingSenderId: "1234567890",
appId: "1:1234567890:web:abcdef"
};
```

This configuration allows the web application to connect to the Firebase database and receive data sent by the ESP32 directly and in real time.

Sending Data to Firebase, after the data is read from the sensor, the ESP32 sends the information to Firebase using the following code:

```
Firebase.pushFloat(fbData, "/pzem/Voltage", Voltage);
Firebase.pushFloat(fbData, "/pzem/current", current);
Firebase.pushFloat(fbData, "/pzem/power", power);
```

4. **Tool Testing**

Figure 4. Tool Testing Process
Source: Author's Processing (2025)

In Figure 4. above, it is explained that the IoT-based energy monitoring and control system is implemented on the main AC panel of the Baitul Marifah Mosque, Poltekbang Surabaya, with the PZEM-004T sensor and contactor connected to the phase cable from the main MCB, using WiFi BaitulMarifah_IoT for stable data transmission, neatly assembled according to electrical safety standards.

Figure 5. Measurement Comparison Process with Clampmeter
Source: Author's Processing (2025)

Figure 5 above shows the accuracy testing process of the IoT power monitoring system using a digital clamp meter as a comparative measuring tool. In this image, the clamp meter shows a current reading of 0.79 A, while the monitoring results from the IoT system can be viewed in real time via a web interface accessed via a smartphone .

Table 1. Comparison Results of SIMPEL with Clampmeter

Current (A)						
Burden	Clamp	PZEM	Difference	Error (%)	Accuracy (%)	Deviation (%)
2 PK AC	7.0	7.0	0	0.00	100.00	0.00
Voltage (V)						
Burden	Clamp	PZEM	Difference	Error (%)	Accuracy (%)	Deviation (%)
2 PK AC	221	222	1	0.45	99.55	0.11
Power (W)						
Burden	Clamp	PZEM	Difference	Error (%)	Accuracy (%)	Deviation (%)
2 PK AC	1547	1554	7	0.45	99.55	0.11
Energy (kWh)						
Burden	Clamp	PZEM	Difference	Error (%)	Accuracy (%)	Deviation (%)
2 PK AC	1,237	1,243	0.006	0.49	99.51	0.17

AVERAGE			
Parameter	Average Error (%)	Average Accuracy (%)	Average Deviation (%)
Current	0.00	100.00	0.00
Voltage	0.45	99.55	0.11
Power	0.45	99.55	0.11
Energy	0.49	99.51	0.17
Overall	0.35	99.65	0.10

Source: Author's Processing (2025)

In table 1. above, it is explained that the accuracy testing of the PZEM-004T sensor-based IoT system was carried out at the Baitul Marifah Mosque by comparing current, voltage, power, and energy measurements on a 2 PK AC against a digital clamp meter. The results show: current (7.0 A) without difference, 100% accuracy, 0.00% deviation; voltage difference 1 V, 99.55% accuracy, 0.11% deviation; power difference 7 W, 99.55% accuracy; energy difference 0.006 kWh, 99.51% accuracy, 0.17% deviation. The average error is 0.35%, accuracy is 99.65%, and the overall deviation is 0.10%, indicating that the system's measurement performance is very good and reliable for monitoring real-time electrical energy consumption, according to field data and the 4D R&D approach.

An IoT-based energy monitoring and control system was tested at the Baitul Marifah Mosque on a 2-PK Panasonic AC for 2 hours (08:00–10:00 WIB) to evaluate the performance of electrical parameter monitoring (voltage, current, power, energy) and automatic control. The PZEM-004T sensor measures data, sent by ESP32 to Firebase via WiFi. The test demonstrated the system's effectiveness in monitoring power consumption and saving energy, with data recorded hourly.

Table 2. Tool Testing Time

No	Testing Time	Voltage (V)	Current (A)	Active Power (W)	Energy (kWh)	AC Status	Information
1	08.00 WIB	222.0	7.00	1,554.0	0.000	ON	Initial data from PZEM004T and ac is on towards stable

2	09.00 WIB	221.5	7.00	1,439.8	0.077	ON	The AC is on steadily
3	10.00 WIB	220.9	0.00	0.0	0.154	OFF	The AC is turned off automatically

Source: Author's Processing (2025)

In table 2. above, it is explained that to measure how much efficiency is achieved, a comparison is made with a conventional scenario where the AC is continuously on for two hours without automatic control.

a. Calculating saved electricity consumption (ΔE)
The electricity saved can be calculated using the following equation:

$$\Delta E = E_{Awal} - E_{Akhir}$$

Information;
$E_{Initial}$: Electricity consumption before savings (kWh)
E_{End} ; Electricity consumption after savings (kWh)

b. Calculating energy cost savings (Rp.)
Calculation of electricity saving costs can use the following equation:

$$\text{Penghematan biaya } = \Delta \text{E} \times Tarif\ per\ kWh$$

c. Calculate the energy saving percentage (%)
Calculation of the percentage of electrical energy savings can use the following equation:

$$\text{Presentase penghematan (\%)} = \frac{\Delta \text{E}}{\text{E}_{Awal}} \times 100\%$$

5. **Web Design (Firebase)**

The design of an IoT-based energy monitoring and control website for the Baitul Marifah Mosque, Poltekbang Surabaya, is responsive and user-friendly using JavaScript, the Firebase SDK, and a project structure in the main HTML siwi3 folder. The structure includes:

1. Main Folder: HTML siwi3
This project's main folder represents the basic structure of an IoT-based electrical energy monitoring and control website system. It contains several configuration files essential for connecting the system to Firebase services and for building and managing the project with Node.js.

2. .firebaser – Firebase Project Configuration
This file contains the identity information of the Firebase project being used, including the project ID and deployment target. This file is very important because it determines where the web application will be deployed when using Firebase Hosting [13] .

3. .gitignore – Git File Filter
Contains a list of files and folders that the Git version control system does not need to track, such as node_modules, local configuration files, and log files. This keeps the repository clean and efficient [14] .

4. database.rules.json – Database Access Rules
This file is used to define read and write access rights to the Firebase Realtime Database. This configuration determines who can access sensor data, device control, and user authentication [15] .

5. firebase.json – Firebase Hosting Configuration
This is the main configuration file for Firebase Hosting. It defines the public directory (where the HTML files are located), caching settings, and rewrites (if using an SPA like React or Vue). This file is essential for web deployment so that the application can be accessed online [16] .

6. package.json – List of Dependencies and Scripts
This file defines all the libraries needed in the project, such as the Firebase SDK, frontend framework, and build and deploy scripts. It also stores project metadata such as name, version, and license [17] .

7. package-lock.json – Locked Version of Dependencies
It locks in the exact version of each dependency to ensure consistent package installation by all users or servers. This prevents system behavior differences due to library version changes.

8. .firebase/ Folder – Firebase Hosting Cache
An internal folder that stores Firebase Hosting's cache information and deployment status. This folder is automatically created by the Firebase CLI and is used to speed up the deployment process by comparing uploaded file versions.

9. node_modules/ Folder – Node.js Project Dependencies
The node_modules folder is a special directory that's automatically created when you install project dependencies using NPM (Node Package Manager). This folder contains all the libraries and external modules required by an application, so it's often quite large. Whenever a developer adds or updates a package using the npm install command, NPM downloads and stores it here.

Some important contents in this folder include @discoveryjs/json-ext, a library for more complex JSON data manipulation. In addition, there is also a .bin/ folder that contains various CLI (Command Line Interface)-

based command scripts, such as webpack for the bundling process, terser for optimizing JavaScript code, and browserslist for managing browser compatibility. Because of its function as a dependency repository, this folder is crucial in the development of Node.js-based projects, although it is generally not committed to the Git repository due to its large size.

With the implementation of this IoT system, it is hoped that the management of electrical energy at the Baitul Marifah Mosque will become more efficient, controlled, and data-driven, thereby reducing monthly electricity subscription costs and becoming an example of the application of smart technology in the management of modern worship facilities.

So that it produces a website like the one below

Figure 6. *Website Dashboard* Display
Source: Author's Processing (2025)

Figure 6 above explains that the "Power Monitoring" web interface for the IoT system at the Baitul Marifah Mosque displays real-time data (225 V voltage, current, power, total energy) and calculates automatic costs based on the rate per kWh (e.g., Rp2,000). Key features include individual control of four relays (Relay 1–4) with ON/OFF buttons, displaying specific voltage, current, power, and energy data per socket, and a "RESET kWh" button to restart recording. Designed to be user-friendly, this interface supports energy efficiency and cost management according to the 4D R&D approach.

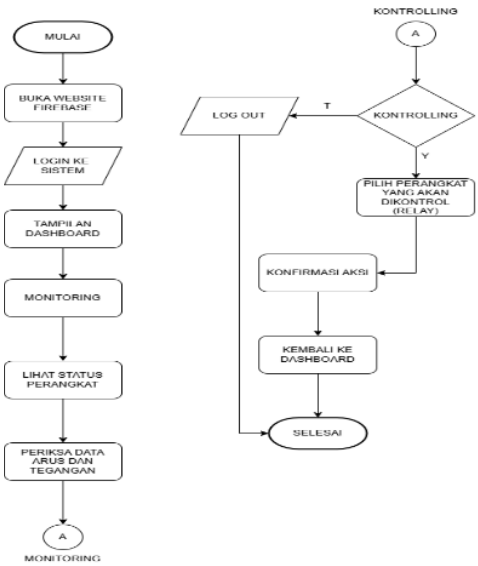

Figure 7. Tool Operation *Flowchart*
Source: Author's Processing (2025)

Place and Time of Research

The research was conducted at **the Baitul Marifah Mosque** , located at the Surabaya Aviation Polytechnic, at Jl. Jemur Andayani I No. 73, Siwalankerto, Wonocolo District, Surabaya, East Java 60236. This research is part of the implementation of the Final Assignment in the Diploma 3 Air Navigation Technology Study Program [18].

All stages of the research followed the development flow of the R&D model, specifically the 4D approach (Define, Design, Develop, Disseminate) [19]. The process began with determining the title and preparing an initial proposal, followed by device design, system development, and testing and reporting. This research took place from March to July 2025, divided into several interconnected phases as shown in Table 1.

Table 3. Research Implementation Schedule

No	Activity Description	Mar	Apr	May	June	Jul
1	Define – Submission and approval of the final project title	✓				
2	Define – Consultation on compiling the background, problem formulation, and objectives	✓	✓			
3	Define – Collection of references and compilation of Chapter 1			✓		
4	Design – Schematic design of IoT tools and systems				✓	
5	Design – Compiling Chapters 2 and 3 according to the system design				✓	
6	Design – Consultation on proposal revision seminar with the					✓

	supervising lecturer					
7	Develop – Seminar proposal and improvement of seminar result documents					✓
8	Develop – Revise the seminar proposal according to the examiner's input					✓
9	Develop – Initial creation and testing of IoT devices					✓
10	Disseminate – Preparation of the final project development report					✓

Source: Author's Processing (2025)

Table 3 shows that the research implementation schedule is structured based on a timeline of activities from March to July, divided into four weeks per month. Activities begin at the *Define stage* with the proposal of a title in the week of March 1–2, followed by consultations on the preparation of the background, problem formulation, and objectives from the week of March 3 to the week of April 1.

The next stage is the collection of references and the preparation of Chapter 1 in the week of May 2–3. In the *Design stage* , the schematic design of the IoT tools and systems is carried out in the week of June 1–2, followed by the preparation of Chapters 2–3 in the week of June 3–4. Consultation on proposal revision seminars takes place in the week of July 1–2. Next, the *Develop stage* includes proposal seminars and document revisions in the week of July 3–4. This schedule shows a structured and systematic approach to completing the research [20].

RESULTS AND FINDINGS

Feasibility Evaluation Results

The evaluation of the feasibility of the IoT-based electrical energy monitoring and control system at the Baitul Marifah Mosque was carried out using a Likert scale questionnaire (1–4) which included four main indicators: Usability, Functionality, Benefit, and Compatibility.

Expert Validation Results

Two expert media validators provided the following assessment results:

Table 4. Summary of Expert Validation Results

No	Validator	Score Obtained	Maximum Score	Percentage	Category
1	Bambang Bagus H., S.SiT, MM, MT	21	24	87.5 %	Very Worthy
2	Yudhistira Khabul, MT	22	24	91.67 %	Very Worthy
	Average	**21.5**	**24**	**89.59 %**	**Very Worthy**

Source: Author's Processing (2025)

In table 4. above, it is explained that to based on the table above, the system obtained an average feasibility of 89.59%, so it was declared "Very Feasible".

Field Observation Results

Through usage trials, the system proved to:

- Effective in real-time monitoring of energy consumption.
- Makes it easier for mosque administrators to control electronic devices (AC, fans, lights).
- It has a simple interface that can be used by non-techies.

Technical Test Results

Sensor Accuracy

Validation of the PZEM-004T sensor with a clamp meter comparator showed a high level of accuracy.

Table 5. PZEM-004T Sensor Accuracy Test Results

Parameter	Clamp Meter Value	PZEM-004T Value	Difference	Accuracy (%)
Current (A)	1.20	1.19	0.01	99.17%
Voltage (V)	220.00	219.50	0.50	99.77%
Power (W)	264.00	263.00	1.00	99.62%
Energy (kWh)	0.300	0.299	0.001	99.67%
Average	-	-	-	**99.65%**

Source: Author's Processing (2025)

In table 5. above, it is explained that these results, an average accuracy of 99.65% was obtained, with an error of only 0.35 **%** .

Energy Saving Effectiveness

Testing was carried out on a 2 PK AC for 2 hours, with a comparison of conditions without IoT control and with IoT control.

Table 6. Energy Efficiency Test Results

Conditions of Use	Energy Consumption (kWh)	Cost (Rp)	Energy Saving	Cost Savings
Without IoT	0.299	432.37	-	-
With IoT	0.154	222.89	0.145 kWh (48.49 %)	Rp209.48 (48.43 %)

Source: Author's Processing (2025)

In table 6. above, it is explained that these Test results show the system is capable of saving energy up to 48.49% and reducing operational costs by almost half.

Discussion of Results

- From the expert feasibility perspective, the system was declared *very feasible* with an average of 89.59%.
- In terms of sensor accuracy, high precision was obtained with an average of 99.65%.
- In terms of energy effectiveness, the system has been proven to be able to save almost 50% of AC electricity consumption.
- Expert and user feedback emphasized the need for improved visual design, the addition of automatic alarm features, and smartphone notifications to enhance future functionality.

Thus, this IoT system is proven to be feasible, accurate, and effective in increasing electrical energy efficiency at the Baitul Marifah Mosque, Poltekbang Surabaya.

CONCLUSION

Based on the research results and discussion, the conclusions that can be drawn are as follows:

1. The system was successfully developed using the 4D (Define, Design, Develop, Disseminate) method, with key components including the ESP32, the PZEM-004T sensor, and Firebase as a cloud-based data communication medium. The prototype is capable of reading voltage, current, power, and electrical energy data through a responsive real-time website dashboard on both desktop and mobile devices. Testing at the mosque proved the system to be stable, integrated, and easily accessible to mosque administrators.
2. The developed IoT system is capable of automatically monitoring electricity consumption using the PZEM-004T sensor. The obtained data is processed into energy information and cost estimates based on applicable electricity tariffs. Test results show the system is capable of significant energy savings with the automatic control feature active, proving the system is not only accurate but also effective in optimizing electricity usage.
3. The PZEM-004T sensor demonstrates excellent accuracy compared to standard measuring instruments. Measurement differences are within acceptable tolerances, making the system reliable and suitable for monitoring power consumption in small to medium-scale installations.
4. Based on an assessment by two media experts, the system was deemed highly suitable for use. The assessment covered aspects of functionality, design, scalability, compatibility with various devices, and ease of use. The experts agreed that the system fulfilled its primary function as an effective energy monitoring solution, although further improvements to the interface and the addition of an automatic notification feature were recommended.

Recommendations

Based on the research results, several suggestions for the development and implementation of a more optimal system in the future are:

1. Future developers or students are advised to consider using alternative current sensors, such as the ACS712, which is more economical yet still quite accurate. Adding a GSM module (e.g., SIM800L) can provide a backup communication path if the Wi-Fi network is disrupted. This integration should be planned early in the design phase to increase system flexibility.
2. Historical energy consumption data recording needs to be strengthened through automatic daily date- and time-based logging. Integrating Firebase with Google Sheets is recommended to ensure data is documented in a structured, accessible, and ready-to-use manner for further analysis or reporting.
3. It's recommended to add an automatic notification feature using Telegram as an early warning tool if power consumption exceeds the limit. After 3–6 months of system use, machine learning algorithms can be applied to analyze energy consumption patterns and predict future usage.
4. The system has the potential to be implemented on a larger scale, such as in schools, offices, or public facilities. The system can be combined with solar panels, creating a smart and environmentally friendly

hybrid system, in line with trends in energy efficiency and sustainability.

5. System development should be based on actual user needs and periodically evaluated within 6–12 months of system deployment. This allows for the collection of empirical data from users and the implementation environment, allowing for more focused development and solutions to address real-world problems.

AUTHORS' CONTRIBUTIONS

1. **Danandaru Saktyasidi** : Principal researcher, responsible for the design, development, implementation, and testing of the IoT system, including data processing and preparation of research manuscripts.
2. **Mr. Ahmad Bahrawi, SE, MT** : Provides strategic guidance and direction regarding the progress of research as Director of the Surabaya Aviation Polytechnic.
3. **Mr. Ade Irfansyah, ST, MT** : Provided support, guidance, and academic guidance during the research process and served as the final project supervisor, including providing technical and conceptual direction regarding the development of the IoT system.
4. **Mr. Yudhis Thiro Kabul Yunior, M.Kom.:** Final project supervisor, providing direction, technical guidance, and input in developing IoT-based prototypes and systems.
5. **Mr. Bambang Bagus Harianto, S.SiT, MM, MT** : Expert validator and Chief Final Project Examiner, provided an evaluation of the system's feasibility, including display quality, functionality, and ease of use.
6. **Mr. Dr. Suyatmo, ST, MT** : Final Project Examiner Secretary, provided input and supervision during the assessment and system validation process.

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REFERENCES

[1] A. M. Madakam, R. Ramaswamy, and S. Tripathi, "Internet of Things (IoT): A literature review," *J. Comput. Commun.* , vol. 3, no. 5, pp. 164–173, 2015.

[2] L. Da Xu, W. He, and S. Li, "Internet of Things in industries: A survey," IEEE Trans. Ind. Informat., vol. 10, no. 4, pp. 2233–2243, Nov. 2014.

[3] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," Future Generation Computer Systems, vol. 29, no. 7, pp. 1645–1660, Sept. 2013.

[4] H. Haron, MZ Jamaludin, and NI Ismail, "Smart mosque: IoT application in energy management," Proc. IEEE Int. Conf. Smart Cities and Green ICT Systems (SMARTGREENS), pp. 321–328, 2019.

[5] MR Alam, M. St-Hilaire, and T. Kunz, "Smart metering and load control for reducing domestic energy consumption," IEEE Trans. Smart Grid, vol. 4, no. 2, pp. 1351–1360, June 2013.

[6] A. Alahi, MS Anwar, and SA Khan, "IoT based energy monitoring system for smart buildings," Proc. IEEE Int. Conf. Innovations in Electrical Engineering and Computational Technologies (ICIEECT), pp. 1–6, 2020.\

[7] AR Putra and S. Hidayat, "Design of IoT-based electrical monitoring using ESP32 and PZEM-004T," J. Phys.: Conf. Ser., vol. 1539, no. 1, pp. 1–7, 2020.

[8] M.A. Hannan, M. Faisal, P.J. Ker, A. Hussain, F. Blaabjerg, and M.M. Hoque, "Review of smart homes energy management systems: Issues and challenges," Renewable and Sustainable Energy Reviews, vol. 144, 111017, 2021.

[9] SH Ahmed and YB Zikria, "Internet of Things (IoT) applications: A review," IEEE Internet Things J., vol. 7, no. 5, pp. 3797–3809, May 2020.

[10] S. Thiagarajan, DS Semmel, and MI Semmel, *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook* . Minneapolis: University of Minnesota, 1974.

[11] B. Mulia, RR Handayani, and AN Putri, "Development of the 4D Model in Educational Research," *Journal of Technology Education* , vol. 12, no. 2, pp. 45–53, 2023.

[12] Ismail, "Application of the Four-D (4D) Model in R&D Research," *Scientific Journal of Technology and Engineering* , vol. 5, no. 1, pp. 10–18, nd

[13] S. Suyatmo, CI Cahyadi, S. Syafriwel, R. Khair, and I. Idris, "Design and Construction of a Prototype Cargo Delivery Robot Based on Arduino Mega with IoT," *J. Sist. Comput. and Inform.* , vol. 1, no. 3, pp. 215–219, 2020.

[14] A. Irfansyah, YTK Yunior, and BB Harianto, "Internet of Things (IoT) Based Trash Can

Monitoring System Using Web Services with the CodeIgniter Framework in the Surabaya Aviation Polytechnic Environment," in *Proceedings of the International Conference of Advanced Transportation, Engineering, and Applied Social Science* , 2023, vol. 2, no. 1, pp. 1050–1053.

[15] N. Pambudiyatno *et al.* , "Technopreneurship-Based Internet of Things (IoT) Workshop in Senior High Schools/Vocational High Schools in Jombang Regency as a Revolutionary Learning Media in the Society 5.0 Era," *J. Public Transp. Community* , vol. 3, no. 2, pp. 77–84, 2023.

[16] YTK Yunior and K. Kusrini, "IoT-Based Water Quality Monitoring System for Aquaculture and Data Management," *Creat. Inf. Technol. J.* , vol. 6, no. 2, pp. 153–164, 2021.

[17] A. Adhicandra, "IoT Implementation for Monitoring Electrical Energy Consumption Using NodeMCU ESP32 and Firebase," *Journal of Electrical and Computer Technology* , vol. 8, no. 1, pp. 55–63, 2024.

[18] Surabaya Aviation Polytechnic, *Campus Profile* . Surabaya: Poltekbang, 2024.

[19] S. Thiagarajan, DS Semmel, and MI Semmel, *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook* . Minneapolis: University of Minnesota, 1974.

[20] J. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* , 5th ed. Thousand Oaks, CA: SAGE, 2018.