Journal of Electrical Engineering and Computer (JEECOM)
Vol. 8, No. 1 (2026), DOI: 10.33650/jeecom.v8i1.16648
p-ISSN: 2715-0410; e-ISSN: 2715-6427

Design and Development of an IoT-Based Household Electrical Energy Monitoring Application for Energy Efficiency

Luluk Suhartini [1*], Fadila [2]
[1,2] Universitas Annuqayah, Sumenep, Indonesia

Article Info

Article history:

Received March 10, 2026
Revised April 27, 2026
Accepted April 29, 2026

Keywords:

Internet of Things (IoT)
Smart Energy Monitoring
Household Electricity Consumption
PZEM-004T
ESP8266

ABSTRACT

Electricity consumption in households is often not properly controlled, which can lead to energy waste and higher electricity bills. Therefore, a system is needed to monitor household electricity usage in real time and provide users with clear information to help them take energy-saving actions. This study designs and develops an Internet of Things (IoT)-based household electricity monitoring application using a PZEM-004T sensor connected to a NodeMCU ESP8266 microcontroller. The measured data, including voltage, current, power, and energy consumption, are transmitted wirelessly to a server and displayed on a custom web-based dashboard without relying on third-party IoT platforms. The application features real-time monitoring and historical consumption records, enabling users to track energy usage trends. Test results show that the system can measure and display data accurately with an average transmission delay of 1–2 seconds, and it helps identify energy-intensive household appliances. Thus, this application can be an effective solution to improve energy efficiency in households.

Corresponding Author:
Luluk Suhartini,
Universitas Annuqayah,, Guluk-Guluk, Sumnep Madura and 69463, Indonesia
Email: lulukkhafi@gmail.com

1. INTRODUCTION

Electrical energy has become an essential necessity in modern society, supporting almost every aspect of daily life, including lighting, cooling, heating, electronic devices, and various household appliances. According to the Indonesian Ministry of Energy and Mineral Resources (ESDM), electricity consumption per capita has continued to increase, reaching 1,337 kWh in 2023 compared to 1,173 kWh in 2022. The government has further targeted an increase to 1,411 kWh per capita in 2024. This growing demand presents significant challenges for both the government and the public in improving energy efficiency and conservation, particularly in the residential sector, which represents one of the largest contributors to national electricity consumption. Therefore, effective electricity consumption management has become increasingly important to ensure sustainable and efficient energy utilization amid rising household electricity demand [1].

One of the primary challenges in residential electricity usage is the lack of an effective monitoring system. Most households still rely on conventional kWh meters that only display total electricity consumption without providing detailed information regarding the energy usage of individual appliances. Consequently, many households experience unexpected increases in electricity bills, mainly due to the intensive use of high-power appliances such as air conditioners, refrigerators, televisions, electric irons, and washing machines [2].

To address energy efficiency issues, the Indonesian government has introduced several policies, including Presidential Instruction No. 13 of 2011 concerning Energy and Water Conservation. This policy encourages households and institutions to use electrical energy more efficiently while promoting sustainable resource management. It also mandates the establishment of supervisory task forces, public awareness programs on energy-saving technologies, and the implementation of fair and efficient energy management practices across various sectors [3]. In addition, the government continues to promote the adoption of energy-efficient household appliances and the transition to induction stoves, which are expected to improve energy efficiency by up to 40%, reduce dependence on liquefied petroleum gas (LPG), and optimize household electricity utilization.

Recent advances in Internet of Things (IoT) technology provide promising solutions for addressing these challenges. IoT enables household electrical devices to communicate through the Internet, allowing users to monitor electricity consumption in real time using smartphone applications. This technology facilitates the identification of appliances with excessive energy consumption while enabling users to remotely control electrical devices in an efficient and convenient manner [4].

Furthermore, integrating web-based platforms into IoT systems offers additional advantages for electricity consumption monitoring. A web dashboard provides greater accessibility by allowing users to monitor energy usage not only through mobile applications but also via computers or other Internet-connected devices. Compared with standalone mobile applications, web-based platforms can support more comprehensive management features, including power consumption threshold settings, automatic notifications when consumption approaches predefined limits, and integration with billing or payment management systems [5].

Previous studies have generally focused on monitoring overall electricity consumption or using mobile applications, without providing a system capable of real-time monitoring of individual device consumption, analyzing the most energy-intensive devices, and offering a web-based dashboard integrated with device control features and electricity usage notifications. Consequently, users have lacked the comprehensive information needed to effectively save energy.

Based on these challenges, there is a need for a technology capable of helping household users monitor, understand, and manage electricity consumption more effectively. Therefore, this study aims to develop an Internet of Things (IoT)-based household electrical energy monitoring application to improve energy usage efficiency.

The novelty of this researh electrical energy monitoring system that not only displays consumption data but also analyzes usage patterns to promote energy efficiency. The system features a standalone web dashboard that operates independently of third-party applications, offering greater flexibility. Additionally, it includes an automatic notification feature that alerts users when power consumption approaches a specific threshold, helping to prevent energy waste. The combination of IoT components—specifically the NodeMCU ESP8266, PZEM-004T sensor, and 5V 3A adapter—was selected to ensure both system accuracy and stability.

2. METHOD

This study aims to design and develop an Internet of Things (IoT)-based household electrical energy monitoring system to improve energy use efficiency. To achieve this objective, the research was conducted through several systematic stages, including requirements analysis, system design, hardware and software development, system integration, implementation, and performance evaluation. Research framework showed on figure 1.

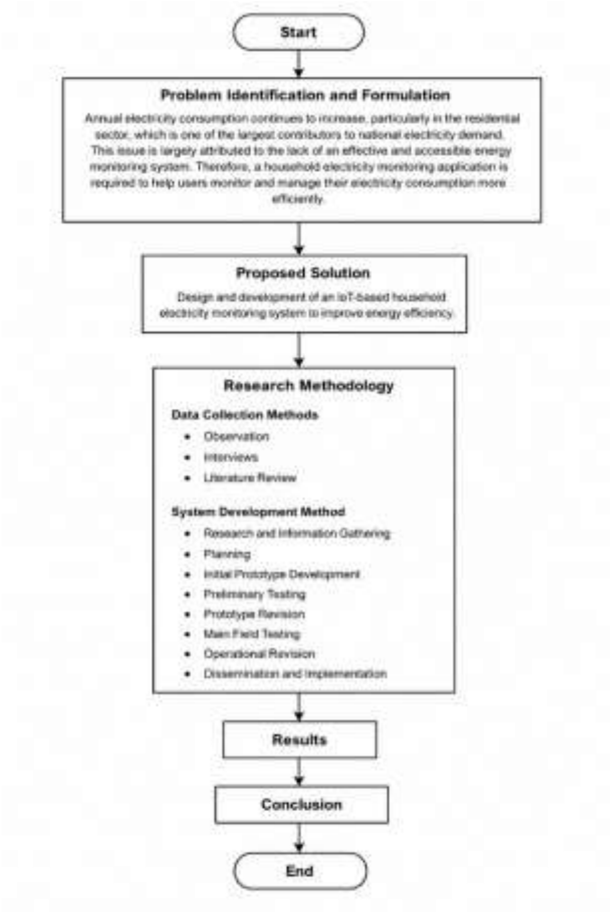

Figure 1. Research Framework

Data were collected using three complementary methods: observation, interviews, and a literature review. The observation was conducted by examining the monthly electricity expenses of several households. The results indicated that conventional electricity bills only provide the total monthly electricity cost without presenting detailed information on the energy consumption of individual household appliances. Consequently, users are unable to identify which appliances consume the most electricity, making it difficult to optimize energy usage and reduce monthly electricity expenses.

To validate the observation findings, interviews were conducted using questionnaires distributed to households in Banjar Barat Village, Gapura District. The interviews aimed to obtain more detailed information regarding household electricity expenditures and users' experiences in managing electricity consumption. The results showed that most respondents experienced difficulties in controlling their monthly electricity costs because they lacked detailed information about the energy consumption of individual appliances. As a result, they could only estimate that continuously operating appliances, such as refrigerators, televisions, and electric fans, were the primary contributors to electricity consumption. However, despite reducing the use of these appliances, respondents reported that they were still unable to significantly reduce their monthly electricity bills.

A literature review was also conducted to establish the theoretical foundation of this research. Relevant references were collected from credible and verified sources, including scientific journal articles, books, conference proceedings, official government publications, and other trusted online resources. The literature review provided a comprehensive understanding of existing studies on household energy monitoring, Internet of Things (IoT) technology, and energy efficiency, while also supporting the design and development of the proposed monitoring system.

For the system development process, this study adopted the Research and Development (R&D) method. This approach was selected because it is suitable for designing, developing, and evaluating a technological product through iterative stages of development and validation. The R&D methodology enables the proposed IoT-based household electricity monitoring system to be systematically designed, implemented, tested, and refined to ensure that it meets user requirements and functions effectively in real-world household environments.

3. RESULTS AND DISCUSSION

At this stage, the information gathered during the data collection process was translated into the design and development of both hardware and software components. The hardware design focused on the IoT-based sensing devices responsible for measuring household electricity consumption, while the software component focused on developing a web-based dashboard for monitoring and managing energy usage. This stage ensured that the identified system requirements were transformed into a functional and integrated monitoring system.

The software architecture was modeled using Unified Modeling Language (UML), including use case, activity, class, and sequence diagrams, to describe the system functionality, workflow, and interactions among system components. In addition, the user interface was designed to provide an intuitive and user-friendly experience, enabling users to monitor and manage household electricity consumption efficiently.

3.1. Class Diagram

The class diagram of the proposed system is presented in Figure 2.

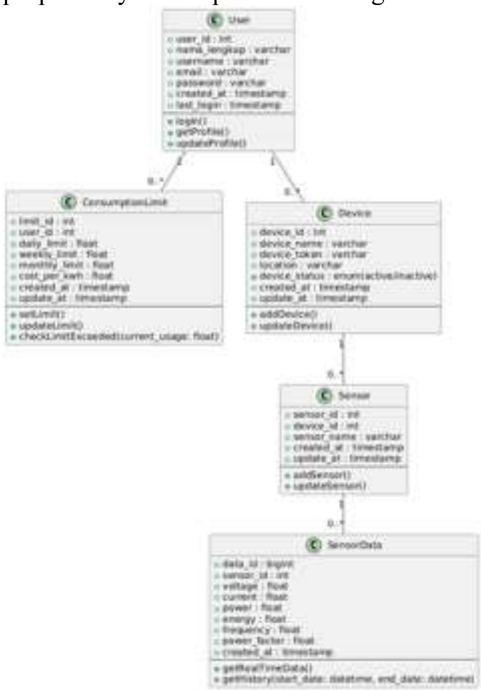

Figure 2. Class Diagram

The class diagram illustrates the architecture of the user-centered household electricity monitoring system. The User class manages user identity and activity information, while the ConsumptionLimit class defines daily, weekly, and monthly electricity consumption thresholds. The Device class represents the household electrical appliances being monitored and is associated with the Sensor class, which is responsible for collecting electrical parameters such as voltage, current, and power consumption.

The collected measurements are stored in the SensorData class, enabling both real-time monitoring and historical data analysis. The relationships among these classes describe the interactions required to support energy consumption monitoring, consumption limit management, and data-driven decision-making. Overall, the class diagram demonstrates the integration of IoT components with a web-based monitoring platform to improve household energy management.

3.2. Sequence Diagram

The sequence diagram illustrates the workflow of user authentication and the automated retrieval of household electricity consumption data. After a successful login, the system retrieves the predefined consumption limits, registered device information, sensor configurations, and the latest sensor measurements. Based on these data, the system continuously evaluates electricity usage against the configured thresholds. When the consumption approaches or exceeds the specified limit, a notification is automatically generated to alert the user.

This sequence demonstrates the interaction between users and system components in supporting real-time electricity monitoring and intelligent energy management. By automating data retrieval and notification processes, the proposed system enhances user convenience while enabling timely decision-making to improve household energy efficiency. The sequence diagram of the proposed system is presented in Figure 3.

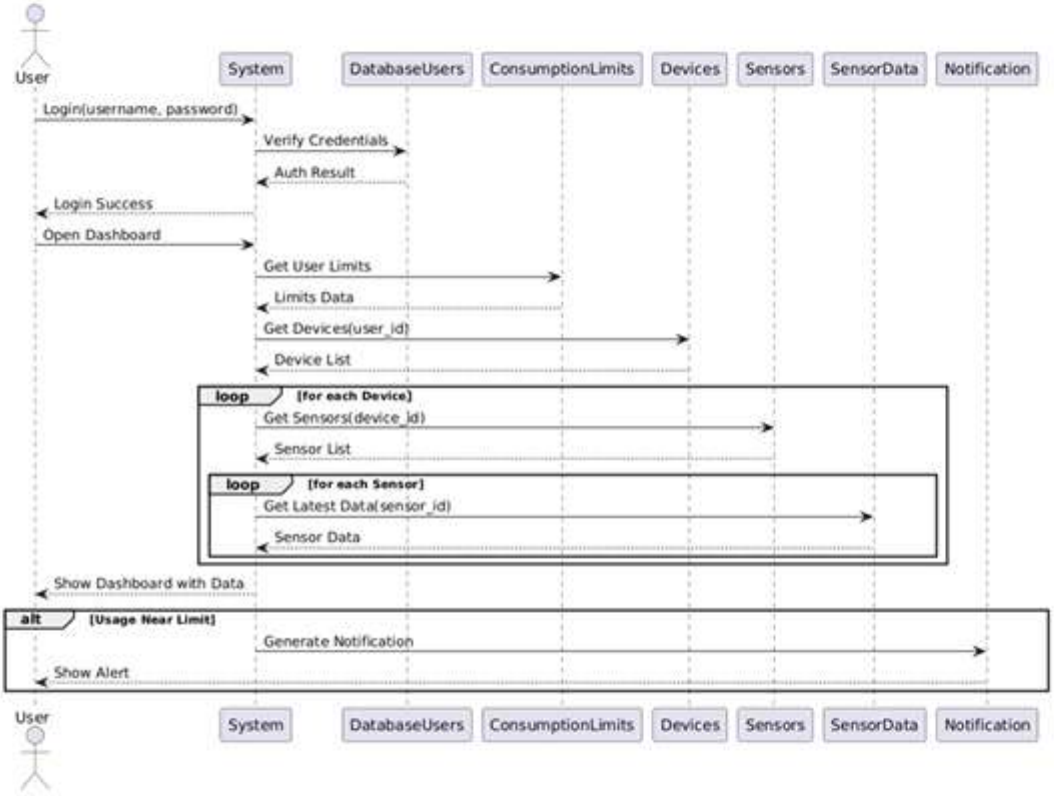

Figure 3. Sequence Diagram

3.3. Hardware Architecture

The proposed IoT-based hardware architecture integrates household electrical devices, energy monitoring modules, and a microcontroller into a unified system for real-time electricity monitoring. Each electrical outlet is connected to a PZEM-004T energy monitoring module, which continuously measures electrical parameters, including voltage, current, active power, energy consumption, frequency, and power factor. These measurements provide detailed information on the electricity usage of individual household appliances, enabling more accurate monitoring and analysis.

The ESP8266 microcontroller functions as the central controller of the system by collecting measurement data from all PZEM-004T modules and transmitting the information to the web-based monitoring platform through a Wi-Fi connection. Communication between the microcontroller and the energy monitoring modules is established via serial communication using jumper wires, ensuring reliable data acquisition and processing. This integrated hardware architecture enables real-time monitoring of household electricity consumption, supports data-driven energy management, and allows users to identify appliances with high energy consumption more effectively. The hardware architecture of the proposed IoT-based monitoring system is illustrated in Figure 4.

ISSN: 2715-6427

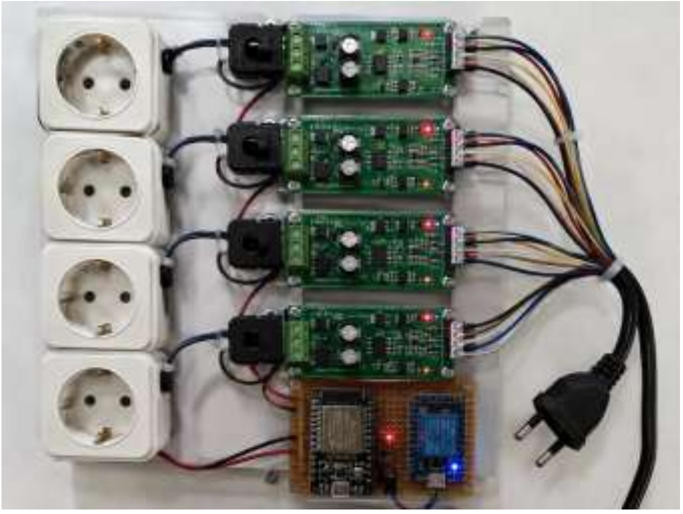
Figure 4. proposed IoT-based hardware architecture

3.2.2. Web-Based Implementation

The web-based dashboard serves as the primary interface for monitoring household electricity consumption in real time. It presents key electrical parameters, including voltage, current, power, and energy consumption, together with a comparison of the current day's energy usage and that of the previous day. The dashboard also provides hourly energy consumption visualizations for daily, weekly, and monthly periods, displays the configured consumption limit and its utilization percentage, estimates electricity costs, and offers quick-action features that simplify system management. These functionalities provide users with a comprehensive overview of energy consumption while supporting more efficient household energy management. The implementation of the dashboard is presented in Figure 5.

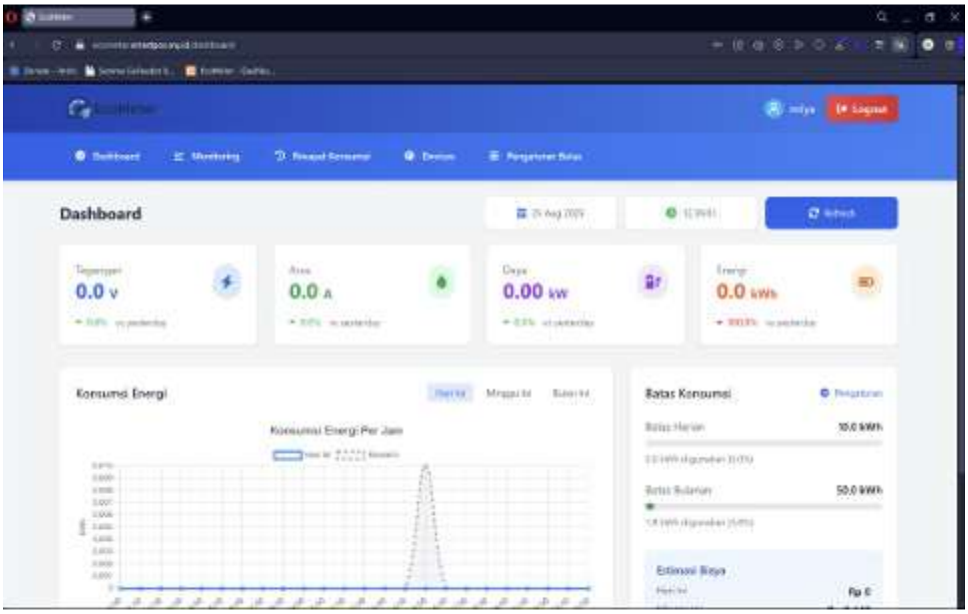

Figure 5. Dashboard

The Devices menu functions as the central interface for managing registered IoT devices and monitoring their operational status. It provides historical information for each connected device, including the device name, unique token, installation location, sensor type, creation date, and activation status. This information enables users to identify, organize, and manage IoT devices efficiently while ensuring reliable integration between the monitoring platform and the deployed hardware. The implementation of the Devices menu is shown in Figure 6.

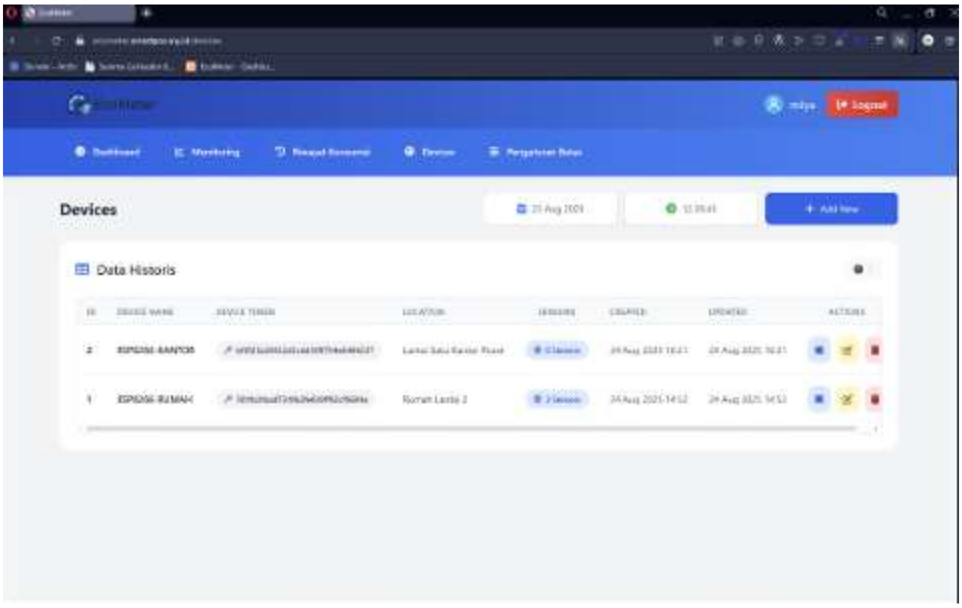

Figure 6. Devices Menu

The Monitoring menu provides detailed information on household electricity consumption based on the selected monitoring period and IoT device. Users can filter the displayed data by date range and device, allowing the system to generate summaries of total energy consumption, estimated electricity costs, the number of active devices, and average power usage. In addition, the sensor data table displays real-time electrical parameters, including voltage, current, active power, energy consumption, frequency, power factor, and estimated electricity costs. These features enable users to analyze electricity consumption patterns more accurately and support informed decision-making for improving household energy efficiency. The implementation of the Monitoring menu is presented in Figure 7.

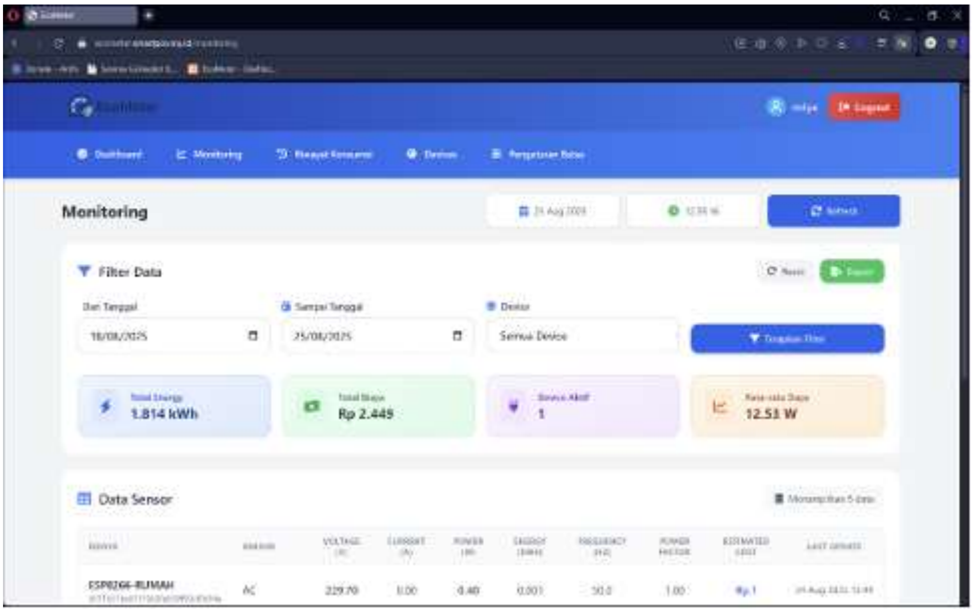

Figure 7. Monitoring menu

4. CONCLUSION

The developed system enables users to monitor electricity consumption more effectively, identify appliances with high energy usage, and make informed decisions to improve household energy efficiency.

Experimental results demonstrate that the proposed system operates reliably with an average data transmission delay of approximately 1–2 seconds while providing accurate and continuous monitoring of electricity consumption. In addition, the historical monitoring feature allows users to analyze daily and monthly energy consumption patterns, thereby increasing awareness of electricity usage and supporting more efficient energy management.

ACKNOWLEDGEMENTS

The authors would like to thank the Department of Informatics Engineering, Faculty of Engineering, Universitas Nurul Jadid, for providing the facilities and academic support required to conduct this research. The authors also appreciate the participation of the households in Banjar Barat Village, Gapura District, who contributed valuable data during the observation and interview stages.

REFERENCES

[1] A. A. Pradana, P. Yuliantoro, and S. Indriyanto, "Perancangan Sistem Monitoring Daya Listrik 1 Fasa Pada Rumah Tangga Berbasis Internet of Things," J. SINTA Sist. Inf. dan Teknol. Komput., vol. 1, no. 1, pp. 1–9, 2024.

[2] M. F. Pela and R. Pramudita, "Sistem Monitoring Penggunaan Daya Listrik Berbasis Internet of Things Pada Rumah Dengan Menggunakan Aplikasi Blynk," Infotech J. Technol. Inf., vol. 7, no. 1, pp. 47–54, 2021.

[3] Kementerian Koordinator Bidang Perekonomian Republik Indonesia, "Dorong Konversi ke Kompor Induksi, Pemerintah Kurangi Ketergantungan kepada Liquefied Petroleum Gas," 2024.

[4] A. Muhammad, B. Prayitno, R. I. Putra, E. Putra, and P. Palupiningsih, "Rancang Bangun Sistem Monitoring dan Controlling Penggunaan Daya Peralatan Listrik Rumah Tangga Menggunakan IoT," Petir, vol. 15, no. 1, pp. 57–62, 2021.

[5] A. Abdullah and R. Risdina, "Sistem Monitoring Konsumsi Listrik Rumah Tangga dan Perbaikan Faktor Daya dengan Modul GSM Berbasis Mikrokontroler ATmega32," MEANS (Media Informasi Analisa dan Sistem), vol. 5, no. 2, pp. 82–87, 2020.

[6] S. Mustafa and U. Muhammad, "Rancang Bangun Sistem Monitoring Penggunaan Daya Listrik Berbasis Smartphone," J. Media Elektr., vol. 17, no. 3, p. 127, 2020.

[7] S. Hadi, A. S. Anas, and L. G. R. Putra, "Rancang Bangun Sistem Monitoring Penggunaan Daya Listrik Berbasis Internet of Things," Circuit: Jurnal Ilmiah Pendidikan Teknik Elektro, vol. 6, no. 1, p. 54, 2022.

[8] S. Bhawana Mulia, A. Ibnu Rosid, et al., "Sistem Pemantauan Penggunaan Listrik Rumah Tangga Dengan Website Berbasis IoT," Journal of Energy and Electrical Engineering, vol. 125, no. 2, pp. 125–131, 2023.

[9] D. H. Manik, R. Nandika, and P. Gunoto, "Penerapan Internet of Things (IoT) Pada Sistem Monitoring Pemakaian Daya Listrik Rumah Tangga Berbasis Mikrokontroler dan Website," Sigma Tek., vol. 4, no. 2, pp. 255–261, 2021.

[10] I. M. S. Radhitya, S. Hadi, and A. Bachtiar, "Monitoring Konsumsi Listrik Rumah Tangga Berbasis Internet of Things Terintegrasi dengan Virtual Private Server," Journal of Bumigora Information Technology, vol. 3, no. 1, pp. 28–37, 2021.

[11] D. Suarna, Z. Zainuddin, and H., "Rancang Bangun Pengontrolan Alat Elektronik Berbasis Internet of Things," Jambura Journal of Electrical and Electronics Engineering, vol. 5, no. 2, pp. 136–142, 2023.

[12] Rifa, R. Sandiari, J. E. Candra, and Z. Munir, "Sistem Monitoring Daya Listrik Berbasis Internet of Things Menggunakan Aplikasi Blynk," Journal of Quancom Quantum Computing, vol. 2, no. 1, pp. 30–34, 2024.

[13] D. S. Lambey, N. Amin, Y. S. Pirade, and R. Santoso, "Analisis Konsumsi Energi Listrik Untuk Pencapaian Efisiensi Energi di Kantor Dewan Perwakilan Rakyat Daerah Kabupaten Tojo Una-Una," Foristek, vol. 11, no. 2, pp. 108–114, 2021.

[14] N. B. Alnavis, R. R. Wirawan, K. I. Solihah, and V. H. Nugroho, "Energi Listrik Berkelanjutan: Potensi dan Tantangan Penyediaan Energi Listrik di Indonesia," Journal of Innovative Materials, Energy, and Sustainable Engineering, vol. 1, no. 2, pp. 119–139, 2024.

[15] A. M. Nasution, S. Y. Moerni, and Y. S. Rambe, "Efisiensi Energi Berkelanjutan: Strategi Desain dan Perhitungan Optimalisasi Efisiensi Energi pada Selubung Bangunan," MARKA (Media Arsitektur dan Kota), vol. 7, no. 2, pp. 167–182, 2024.

[16] P. Raja, D. S. Kumar, D. S. Yadav, and D. T. Singh, "The Internet of Things (IoT): A Review of Concepts, Technologies, and Applications," International Journal of Information Technology and Computer Engineering, no. 32, pp. 21–32, 2023.

[17] M. Waruwu, "Metode Penelitian dan Pengembangan (R&D): Konsep, Jenis, Tahapan dan Kelebihan," Jurnal Ilmiah Profesi Pendidik., vol. 9, no. 2, pp. 1220–1230, 2024.

[18] Y. D. Wijaya and M. W. Astuti, "Pengujian Black Box Sistem Informasi Penilaian Kinerja Karyawan PT INKA (Persero) Berbasis Equivalence Partitions," Jurnal Digital Teknologi Informasi, vol. 4, no. 1, p. 22, 2021.