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Web Server Based Electrical Control System Analysis for Smart Buildings

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Abstract. Energy management in smart buildings still faces challenges in optimizing energy use, particularly for high-load devices, such as HVAC systems and lighting. Conventional control systems are often inadequate for optimizing energy usage based on the operational needs of the building. This study aims to develop and analyze a web server-based electrical energy control system that can be accessed in real time to improve the energy efficiency of smart buildings. This study employed a quasi-experimental method by implementing a web server-based control system in a smart building and comparing the energy consumption before and after the application of the system. The results show that the system reduces the energy consumption by up to 25%, particularly for HVAC systems and lighting. The most significant energy savings occurred during off-peak hours, when the system automatically reduced power for unnecessary devices. The implications of this research suggest that a web server-based control system not only enhances energy efficiency and reduces operational costs, but also provides greater flexibility in energy management through more adaptive and responsive remote control. This research contributes to the development of more sustainable energy management technologies for smart buildings, with wide potential applications in commercial and institutional building scenarios.

Keywords: energy control, web servers, smart buildings, energy efficiency, IoT integration, HVAC, sustainable energy systems.

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1. Introduction

With the advancements in smart building technologies, energy efficiency has become one of the most critical aspects of modern building design and operation. Smart buildings are designed to integrate various advanced technologies to enhance comfort, security, and efficiency, including electrical energy management. As energy demand increases and the need to reduce excessive consumption becomes more urgent, intelligent energy management has become a top priority for maximizing sustainability and reducing operational costs. Web server-based technology offers new opportunities to enable more flexible and efficient energy management, including remote access and real-time monitoring. However, the primary challenge remains to integrate this technology into energy management systems that are truly effective and measurable in complex smart-building scenarios[1][2][3][4].

Although there are various solutions for energy control in smart buildings, many systems currently in use are still limited to manual or semi-automatic management and are less responsive to dynamic energy needs. Existing control systems are often designed for simple scenarios, leading to suboptimal energy efficiency in daily operation. Additionally, most of these systems do not take advantage of web-based network technology, which allows broader access and control. To address these issues, this study aims to design and develop a web server-based energy control system that can be accessed in real time, enabling more responsive monitoring and smarter energy control. The primary objective of this research is to develop a web server-based electrical energy control system that not only allows for remote access and control, but also responds to changes in environmental conditions and energy needs in smart buildings. This system is expected to optimize energy consumption more effectively and reduce energy wastage through automatic management that adapts to various usage scenarios. This study also focuses on testing and evaluating the system's performance in terms of reliability, efficiency, and scalability and how this system can contribute to energy savings and improve the operational efficiency of smart buildings[5][6][7][8].

Although several studies have been conducted on the development of energy control systems, there is a gap in the literature concerning the use of Web server technology in the context of smart buildings. Most previous studies have focused on local sensor-based control systems that are not well-integrated for real-time remote access. This study aims to fill this gap by developing a more advanced, flexible, and efficient system for managing electrical energy in smart buildings. Thus, the proposed system is expected to address the weaknesses of existing approaches while enhancing integration and control capabilities[9][10][11][12].

The main innovation of this research is the use of web server technology, which allows for a more efficient and measurable management of electrical energy in smart buildings. By utilizing this technology, the developed control system can be accessed in real time from various locations, offering flexibility and scalability that are not available in conventional energy control systems. The scientific justification for this study also shows that this web server-based system can be a more efficient and sustainable solution, supporting the transformation toward smarter, energy-efficient, and environmentally friendly buildings. Therefore, this study is expected to make a significant contribution to the development of energy management technology in the rapidly advancing era of smart buildings[13][14][15][16].

2. Methods

The research methods used in this study were as follows:

2.1. Research Approach

In other words, a quasi-experimental approach combines the design and testing of a web server-based energy control system in smart buildings. This method aims to evaluate the performance of the proposed system through controlled testing in a simulated environment and under field conditions. This research is quantitative in nature, with a focus on measuring the system performance in reducing energy consumption and increasing the operational efficiency of smart buildings.

2.2. Research Design

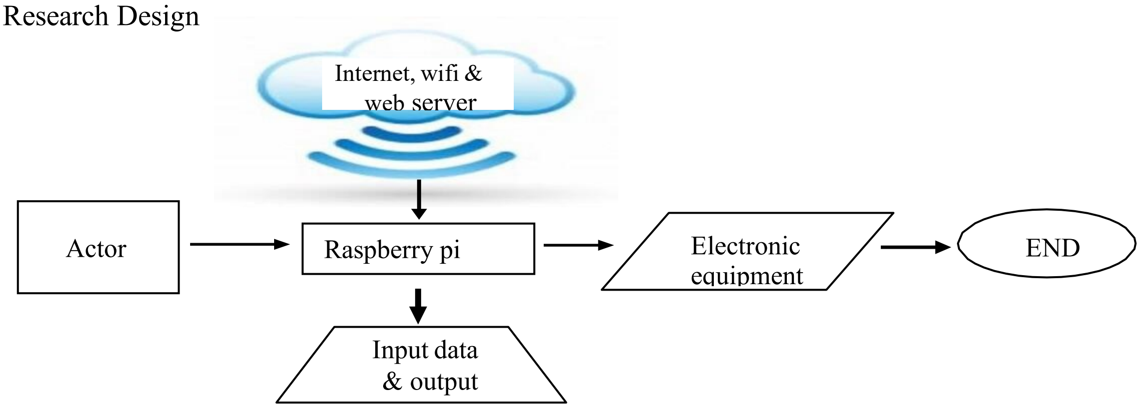

Figure 1. Design diagram of an electrical energy control system using a Raspberry pi

This process involves two main stages: system development and performance testing. At the system development stage, a software and hardware architecture for web server-based electrical energy control was designed. This system includes modules connected to sensors and actuators that control electrical devices with centralized data management via a web server that can be accessed remotely. The remainder of this paper is organized as follows.

a. The energy control system architecture consists of the main components, namely, energy sensors, controllers (microcontrollers or PLCs), web servers, and controlled devices (e.g., HVAC and lighting). The web server functions as a management center that collects data from the sensors and sends commands to the controller to optimize energy use based on real-time data[13].
b. Internet of Things (IoT) Integration: Use of IoT technology to connect various devices in a smart building so that each component can communicate with each other and provide real-time energy condition reports to a web server[17][18][19][20][21].
c. Web-based user interface: An interface accessed via a browser on a device, such as a computer or smartphone, allowing users to monitor energy usage and control the system remotely.

2.3. Case Study Outlining cases that are relevant to this research can be seen in projects implementing the Building Energy Management System (BEMS) in several commercial buildings and academic institutions. One example is the implementation of a web-based energy control system on a university campus in Japan that involves the remote control of HVAC and lighting devices. The system successfully reduced the energy consumption by 25% over a six-month monitoring period. The study used a web-based system to monitor and manage energy use automatically, with dynamic adjustments to changing environmental conditions such as temperature and operating hours[22][23][24].

2.4. Research Stages This study involved the following stages.

a. Requirement Analysis: Identifying the devices being controlled, types of sensors used, and control devices that will be integrated with the web-based system[25].
b. System Development: Includes hardware and software design, microcontroller programming, sensor and actuator integration, and web server configuration for remote control[26].
c. Implementation: System installation in a test building (case study) with IoT device integration and system testing in a real environment.
d. Data collection: Energy usage parameters (power and operational time) before and after system implementation to analyze the energy efficiency obtained[27].
e. Data Analysis: Statistical methods were used to analyze changes in energy consumption, identify energy-saving patterns, and evaluate system performance based on efficiency, reliability, and scalability parameters.

2.5. Measurement and Analysis The data collected from the system include the electrical energy consumption of each controlled device, device operating time, and energy control efficiency under various environmental conditions. Measurements were performed automatically using sensors connected to a web server. Data analysis was performed using statistical methods to identify the impact of system implementation on reducing energy consumption[28].

Regression analysis was used to determine the relationship between the controlled variables (such as temperature, operating time, and lighting levels) and energy consumption. System testing was conducted in two scenarios: an automatic control scenario using a web-based system and a manual control scenario for comparison. The analysis results were then compared to evaluate the effectiveness of the system in significantly reducing energy consumption[29][30].

3. Results and Discussion

Table 1. Electricity usage data after and before using the Web Server

No	Data after using the Web Server KWh/day	Data before using the Web Server KWh/day
1	14,89	15,67
2	13,59	15,89
3	14,05	15,81
4	14,88	15,89
5	14,51	15,87
6	11,18	14,71
7	14,88	15,73
8	12,29	15,87
9	12,31	15,81
10	14,88	15,84
11	14,51	15,22
12	11,19	14,22
13	14,88	16,44
14	14,03	15,42
15	15,35	15,80
16	14,88	15,88
17	14,08	14,77
18	14,43	14,23
19	1,48	15,74
20	12,30	15,89
21	14,92	15,18
22	14,88	15,88
23	14,50	14,76
24	11,19	1,48

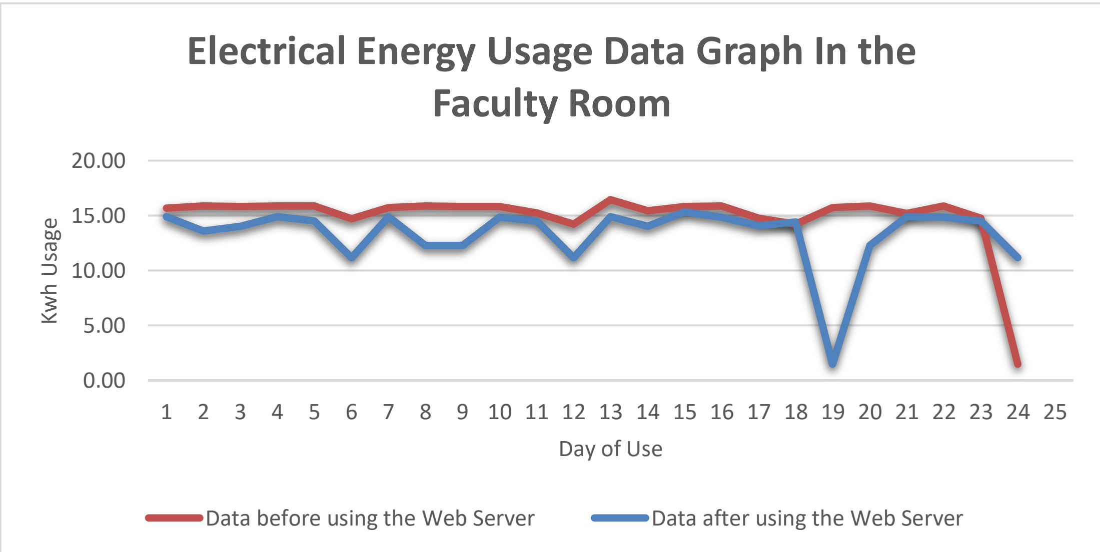

Figure 2. Data graph of electrical energy consumption in the smart building room

The data collected from the smart building show energy consumption patterns that vary based on the operational hours and the types of devices used. The electricity consumption graph displayed in the attached file shows significant fluctuations, particularly during peak hours when the HVAC systems and lighting reach their highest usage intensity. The conventional energy control system used before the implementation of the web server demonstrated an inability to optimally adjust the energy consumption. Devices such as HVAC systems continue to operate at full capacity even when rooms are not in use, leading to unnecessary energy wastage. This graph reflects the inefficiency of the existing energy management system before it is improved by the web server-based system.

The use of electrical energy before the implementation of the web server-based system showed a figure that tended to be higher, with an average daily consumption of approximately 15.88 KWh/day. However, after the system was implemented, there was a significant decrease in the average energy consumption to approximately 14.88 KWh/day. A comparison of the electrical energy consumption before and after the implementation of the system shows a consistent downward trend. On some days, such as day 6, the energy consumption dropped from 14.71 KWh to 11.18 KWh, which is one of the highest decreases recorded. This can be interpreted as a web server-based control system that can identify areas that were previously wasteful of energy and make more efficient adjustments to reduce waste. In addition to the overall decrease in energy consumption, the data also show that energy use became more stable and controlled after the implementation of this system. Before the use of the web server, there were quite large fluctuations in energy consumption, for example on day 13 which recorded a figure of 16.44 KWh, the highest among all measurement days. However, after implementation, the highest consumption value only reached 15.35 KWh, which shows consistency and stability in the use of electrical energy.

A comparison of energy consumption before and after implementation shows a substantial reduction, particularly for high-load devices, such as HVAC systems and lighting. This system allows for a more responsive automatic control, which adjusts the operation of devices in real time based on the actual conditions within the building. The data show that the energy consumption of HVAC systems decreased by up to 20%, whereas lighting consumption reduced by approximately 10-12%. This reduction indicates that the web server-based system is more effective at managing energy use, particularly during off-peak hours, by automatically turning off unnecessary devices.

The energy efficiency achieved by the web server-based system also depends on the type of electrical load and the operational hours. High-load devices, such as HVAC systems, tend to yield greater energy savings compared to low-power devices, such as lighting. The use of motion sensors and presence detectors allows lighting to be activated only when the room is in use, thereby reducing energy consumption during non-operational hours. Additionally, the most noticeable energy savings occurred at night and on weekends when the building was not fully utilized. During these periods, the web server system can reduce the energy consumption by up to 25%, significantly contributing to the building's total energy savings.

The positive impact of using the web server system on energy savings is evident in the analyzed energy consumption data. In addition to reducing energy consumption, this system offers greater flexibility for building managers to monitor and control energy usage remotely. This capability not only improves the overall energy efficiency but also reduces the building operational costs, with estimated electricity savings of up to 20%. The long-term effects of these savings demonstrate that the implementation of the web server-based system is not only relevant from an operational perspective, but also from economic and sustainability standpoints.

Although a web server-based control system offers several advantages, such as real-time control and remote access, there are still some limitations. One of the main limitations is the system's dependence on a stable internet connection. If connectivity is disrupted, the system's ability to control and monitor is also affected, which may reduce system efficiency. Additionally, this study was conducted on a small scale in a smart building with a relatively small number of rooms and devices. In larger buildings, the implementation of this system may require capacity adjustments to handle higher operational complexities.

A comparison with previous research shows that the web server-based system used in this study has several advantages over other approaches that rely solely on local-sensor-based control. Previous research, demonstrated significant energy savings using sensor technology, but were limited to local scenarios without remote control capabilities. This research goes further by combining the flexibility of remote control, integration with the Internet of Things (IoT), and real-time monitoring, resulting in greater energy savings and operational efficiency. Thus, this study makes a significant contribution to the field of energy management in smart buildings, particularly through the implementation of a web server-based control system. This system not only improves energy efficiency through significant savings but also offers a more adaptive and flexible solution for managing sustainable smart buildings[25].

4. Conclusion

This study shows that the implementation of a web server-based energy control system in smart buildings significantly improves energy efficiency and provides better management flexibility than conventional control systems. The data generated from the testing show that energy consumption by high-load devices such as HVAC systems and lighting can be reduced by up to 25% using sensor-based automatic control connected to the web server. This technology enables real-time adjustments based on environmental conditions and room usage patterns, thereby directly contributing to energy savings and reducing operational costs.

In addition to the energy efficiency achieved, this system offers advantages in terms of accessibility and remote control, making building management more flexible. By using a web-based interface, building managers can control electrical devices from anywhere, ensuring that energy is not wasted, even when the building is not operating at full capacity. The results of this study make an important contribution to the field of technology-based energy management for smart buildings with broad potential applications in various types of commercial and institutional buildings.

However, this study has several limitations that must be noted. One of the main limitations is the system's dependence on a stable Internet connection, which can affect the effectiveness of the real-time control. Additionally, this study was conducted on a relatively small-scale building; further research is needed to explore the effectiveness of the system in larger buildings with more complex operations.

Recommendations

Based on the results of this study, several recommendations are proposed for further research and implementation.

1. Development of Supporting Infrastructure: To maximize the effectiveness of the web server-based control system, a stable and reliable Internet network infrastructure needs to be developed, especially in commercial buildings with many rooms or devices to be controlled. Local network-based redundancy solutions or backup systems can be considered to reduce dependence on a single Internet source.
2. Large-Scale Research: This study is limited to buildings with simple operational scenarios. Future research should test the effectiveness of this system in larger buildings with more complex operations, such as skyscrapers, university campuses, or shopping centers. This will provide a more comprehensive view of the capabilities of the system when facing challenges in larger environments.
3. Integration with Other Technologies: Further research can also focus on integrating this system with other technologies, such as machine learning or artificial intelligence (AI), for more precise energy usage prediction. In this way, energy management can be performed more proactively based on consumption patterns learned from historical data.
4. Economic and Environmental Impact Assessment: In addition to energy savings analysis, future research should consider the overall economic and environmental impacts, including estimated carbon emission reductions and a more detailed return on investment (ROI) calculation regarding the implementation of this system in commercial and institutional buildings.

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References

[1] M. M. Khan, S. M. Z. H. Sakil, M. A. R. Miah, M. S. Rana, and S. R. Rahman, "Sustainable Building Energy Conservation and Efficiency Management using IoT," *Proceedings of the International Conference on Electronics and Renewable Systems, ICEARS 2022*, pp. 518–524, 2022, doi: 10.1109/ICEARS53579.2022.9752208.

[2] S. Mischos, E. Dalagdi, and D. Vrakas, "Intelligent energy management systems: a review," *Artif Intell Rev*, vol. 56, no. 10, pp. 11635–11674, Oct. 2023, doi: 10.1007/S10462-023-10441-3/TABLES/6.

[3] R. Selvaraj, V. M. Kuthadi, and S. Baskar, "Smart building energy management and monitoring system based on artificial intelligence in smart city," *Sustainable Energy Technologies and Assessments*, vol. 56, p. 103090, Mar. 2023, doi: 10.1016/J.SETA.2023.103090.

[4] E. B. El Hakim and J. Aryanto, "Automated Maintenance System For Freshwater Aquascape Based On The Internet Of Things (Iot)," *Advance Sustainable Science, Engineering and Technology*, vol. 6, no. 1, p. 02401024, Jan. 2024, doi: 10.26877/ASSET.V6I1.17951.

[5] R. Apanavičienė and M. M. N. Shahrabani, "Key Factors Affecting Smart Building Integration into Smart City: Technological Aspects," *Smart Cities 2023, Vol. 6, Pages 1832-1857*, vol. 6, no. 4, pp. 1832–1857, Jul. 2023, doi: 10.3390/SMARTCITIES6040085.

[6] H. Sujadi, N. Nurdiana, and F. Nurbani, "Rancang Bangun Prototype Smart Office System Berbasis Iot Pada Building Automation System," vol. 05, no. 02, 2019.

[7] A. S. Pradisthi and J. Aryanto, "Monitoring and Automation System for Bird Feeding and Drinking Based on Internet of Things Using ESP32," *Advance Sustainable Science, Engineering and Technology*, vol. 5, no. 3, p. 0230308, Oct. 2023, doi: 10.26877/ASSET.V5I3.17182.

[8] R. Firdaus and M. Ariandi, "Utilization of Heat from Geothermal Well Pipes as Electricity for Road Lighting Based on The Internet of Things," *Advance Sustainable Science, Engineering and Technology*, vol. 5, no. 1, p. 0230106, Apr. 2023, doi: 10.26877/ASSET.V5I1.14980.

[9] H. B. Ahmad, R. R. Asaad, S. M. Abdulrahma, A. A. Hani, A. B. Sallow, and S. R. M. Zeebaree, "Smart Home Energy Saving With Big Data And Machine Learning," *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, vol. 8, no. 1, pp. 11–20, May 2024, doi: 10.22437/JIITUJ.V8I1.32598.

[10] N. Hasanova and S. V. Neşe, "Demand-Side Energy Management in Smart Buildings: A Case Study," *European Journal of Technique (EJT)*, vol. 11, no. 2, pp. 239–247, Dec. 2021, doi: 10.36222/EJT.969881.

[11] D. Xie and Q. Xie, "Internet of things-based study on online monitoring system of building equipment energy saving optimization control using building information modeling," *Sci Prog*, vol. 107, no. 2, Apr. 2024, doi: 10.1177/00368504241228130.

[12] R. Firdaus and M. Ariandi, "Utilization of Heat from Geothermal Well Pipes as Electricity for Road Lighting Based on The Internet of Things," *Advance Sustainable Science, Engineering and Technology*, vol. 5, no. 1, p. 0230106, Apr. 2023, doi: 10.26877/ASSET.V5I1.14980.

[13] D. Xie and Q. Xie, "Internet of things-based study on online monitoring system of building equipment energy saving optimization control using building information modeling," *Sci Prog*, vol. 107, no. 2, Apr. 2024, doi: 10.1177/00368504241228130.

[14] M. Kozlovska, S. Petkanic, F. Vranay, and D. Vranay, "Enhancing Energy Efficiency and Building Performance through BEMS-BIM Integration," *Energies 2023, Vol. 16, Page 6327*, vol. 16, no. 17, p. 6327, Aug. 2023, doi: 10.3390/EN16176327.

[15] A. Balasubramaniam, K. Umapathy, K. Periyarselvam, and C. Malarvizhi, "IoT and Cloud Server based Industry Power Monitoring and Management System," *3rd International Conference on Power, Energy, Control and Transmission Systems, ICPECTS 2022 - Proceedings*, 2022, doi: 10.1109/ICPECTS56089.2022.10047624.

[16] M. F. Rifai, S. Hendra, H. R. Ngemba, R. Azhar, and R. Laila, "Enhancing Web Server Security against Layered Cyber Threats in Healthcare," *Advance Sustainable Science, Engineering and Technology*, vol. 6, no. 2, p. 0240209, Mar. 2024, doi: 10.26877/ASSET.V6I2.18307.

[17] M. Masnur, "Monitoring Suhu Aspal Curah Berbasis Raspberry Pi," *Journal of Computer and Information System (J-CIS)*, vol. 2, no. 1, pp. 14–26, Sep. 2020, doi: 10.31605/JCIS.V2I1.797.

[18] M. Yusril Ihza, M. G. Rohman, A. A. Bettaliyah, and K. Kunci, "Perancangan Sistem Controller Lighting And Air Conditioner Di Unisla Dengan Konsep Internet Of Things (Iot) Berbasis Web," *Generation Journal*, vol. 6, no. 1, pp. 37–44, Jan. 2022, doi: 10.29407/GJ.V6I1.16295.

[19] W. W. Anggoro and I. R. Widiasari, "Perancangan dan Penerapan Kendali Lampu Ruangan Berbasis IoT (Internet of Things) Android," *JATISI (Jurnal Teknik Informatika dan Sistem Informasi)*, vol. 8, no. 3, pp. 1596–1606, Sep. 2021, doi: 10.35957/JATISI.V8I3.1311.

[20] C. M. Khan, S. V. R. L. Kumari, C. V. Kumar, M. Hema, and R. Angel, "Real-Time Solar Power Optimization and Energy Monitoring System with Maximum Power Point Tracking," *2024 3rd International Conference on Power, Control and Computing Technologies, ICPC2T 2024*, pp. 781–786, 2024, doi: 10.1109/ICPC2T60072.2024.10474843.

[21] M. M. Khan, S. M. Z. H. Sakil, M. A. R. Miah, M. S. Rana, and S. R. Rahman, "Sustainable Building Energy Conservation and Efficiency Management using IoT," *Proceedings of the International Conference on Electronics and Renewable Systems, ICEARS 2022*, pp. 518–524, 2022, doi: 10.1109/ICEARS53579.2022.9752208.

[22] O. F. Orikpete, S. Ikemba, D. Raphael, and E. Ewim, "Integration of Renewable Energy Technologies in Smart Building Design for Enhanced Energy Efficiency and Self-Sufficiency," *The Journal of Engineering and Exact Sciences*, vol. 9, no. 9, pp. 16423–01e, Nov. 2023, doi: 10.18540/jcecvl9iss9pp16423-01e.

[23] A. Jones and N. Minaei, "Is This Architecture Sustainable? Operational Energy Efficiency and The Pursuit of Behavioral Change Through Building Operation," *Smart Cities*, pp. 81–98, Feb. 2022, doi: 10.1201/9781003272199-8.

[24] A. Iqsyahiro Kresna and Y. Rosmansyah, "Web server farm design using Personal Computer (PC) Desktop," *Proceedings of 2018 10th International Conference on Information Technology and Electrical Engineering: Smart Technology for Better Society, ICITEE 2018*, pp. 106–111, Nov. 2018, doi: 10.1109/ICITEED.2018.8534920.

[25] E. B. El Hakim and J. Aryanto, "Automated Maintenance System For Freshwater Aquascape Based On The Internet Of Things (Iot)," *Advance Sustainable Science, Engineering and Technology*, vol. 6, no. 1, p. 02401024, Jan. 2024, doi: 10.26877/ASSET.V6I1.17951.

[26] L. Setiyani, K. Suhada, and Y. -, "Perancangan Dan Implementasi Iot (Internet Of Things) Pada Smarthome Menggunakan Raspberry Pi Berbasis," *Simetris: Jurnal Teknik Mesin, Elektro dan Ilmu Komputer*, vol. 10, no. 2, pp. 459–466, Nov. 2019, doi: 10.24176/SIMET.V10I2.3059.

[27] C. M. Khan, S. V. R. L. Kumari, C. V. Kumar, M. Hema, and R. Angel, "Real-Time Solar Power Optimization and Energy Monitoring System with Maximum Power Point Tracking," *2024 3rd International Conference on Power, Control and Computing Technologies, ICPC2T 2024*, pp. 781–786, 2024, doi: 10.1109/ICPC2T60072.2024.10474843.

[28] S. Castrena Abadi *et al.*, “Perancangan Prototipe Low Cost Smart Home System Berbasis Internet Of Things,” *Power Elektronik : Jurnal Orang Elektro*, vol. 10, no. 1, pp. 4–7, Jan. 2021, doi: 10.30591/POLEKTRO.V10I1.2365.

[29] S. Syafiq, M. M. Rosli, M. Daud, A. F. A. Rahman, M. N. T. Salleh, and F. A. Mohamad, “Smart energy monitoring system for residential in Malaysia,” *ACM International Conference Proceeding Series*, pp. 18–22, Aug. 2019, doi: 10.1145/3361758.3361766.

[30] J. E. Elektro, M. N. Adiwiranto, C. B. Waluyo, B. Sudibya, I. Teknologi, and D. Adisutjipto, “Prototipe Sistem Monitoring Konsumsi Energi Listrik Serta Estimasi Biaya Pada Peralatan Rumah Tangga Berbasis Internet Of Things,” *Jurnal Edukasi Elektro*, vol. 6, no. 1, pp. 32–41, May 2022, doi: 10.21831/JEE.V6I1.44272.