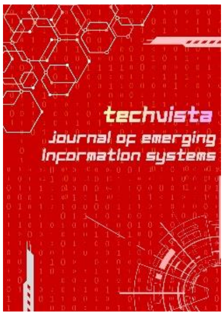

ISSN (Print)
ISSN (Online)

TechVista Journal Emerging Information Systems

Vol. 1 No. 1, 2025 (Page: 21-29)
DOI:

Implementation of IoT System for Household Electrical Energy Monitoring

Putra Mahendra[1]

[1]Faculty of Engineering, Muslim University of Indonesia

Article History

Keywords

IoT-Based Energy Monitoring
Household Energy Efficiency
User Engagement
Sustainability Practices

Abstract

This study investigates the effectiveness of implementing an IoT-based system for household electrical energy monitoring to promote energy efficiency and user engagement. Using a quasi-experimental pre-test/post-test design, the study compared the energy consumption, engagement levels, and energy awareness of two groups: an experimental group utilizing the IoT system and a control group relying on traditional energy monitoring methods. Data were collected through real-time energy usage logs, user surveys, and observational records over a 12-week period. Results revealed a significant 20% reduction in energy consumption for the experimental group, compared to a negligible 1.28% reduction in the control group. Additionally, participants in the experimental group reported higher levels of energy awareness and actively engaged with the system, with 85% responding to alerts and 92% frequently checking real-time data. These findings confirm the effectiveness of IoT systems in optimizing household energy usage and promoting sustainable practices. However, challenges such as behavioral inertia, system usability, and data privacy require further attention to ensure widespread adoption. This study underscores the potential of IoT technologies to transform residential energy management and contribute to global energy sustainability goals.

Introduction

The increasing global demand for energy and the rising concerns about environmental sustainability have made energy efficiency a top priority across various sectors, including households. Electricity consumption in households constitutes a significant portion of overall energy demand, and effective monitoring systems are critical to managing and reducing this consumption (Fischer, 2008; Siano, 2014). In recent years, the advent of the Internet of Things (IoT) has introduced innovative solutions for energy monitoring, enabling real-time data acquisition, analysis, and actionable insights for energy optimization. IoT-based systems leverage interconnected devices to monitor and control electrical energy usage more efficiently, offering a pathway to smarter and greener households.

[1] Corresponding Author: Putra Mahendra, Address: Jl. Urip Sumoharjo No.km.5, Panaikang, Kec. Panakkukang, Kota Makassar, Sulawesi Selatan 90231

Traditional household energy monitoring systems often rely on manual processes or rudimentary smart meters that provide limited data, such as total energy usage over a given time period (Hurst et al., 2020). These methods fail to provide detailed insights into the consumption patterns of specific appliances or to detect inefficiencies and anomalies. As a result, consumers often lack the information necessary to implement energy-saving practices effectively (Hurst et al., 2020). IoT-based solutions overcome these limitations by employing sensors, actuators, and advanced analytics, offering granular data on energy consumption and real-time feedback to users. Furthermore, IoT systems enable remote monitoring and control of household devices, promoting energy conservation without compromising convenience or comfort (Ford et al., 2017).

An IoT-enabled energy monitoring system typically consists of hardware components, such as smart sensors and controllers, and software platforms that process, store, and visualize data (El-Afifi et al., 2024). These systems can also integrate with advanced technologies such as machine learning and artificial intelligence to identify consumption patterns, predict future usage, and provide customized recommendations for reducing energy wastage (Himeur et al., 2021). Additionally, cloud-based platforms facilitate data storage and remote access, allowing users to monitor their energy consumption through mobile or web applications from anywhere. Such functionalities make IoT systems a vital tool for promoting energy efficiency and environmental sustainability in households.

Several recent studies have demonstrated the effectiveness of IoT systems for energy monitoring in households. For instance, Albraheem et al. (2023) developed an IoT-based energy monitoring system that uses smart plugs to measure the consumption of individual appliances. Their results indicated that detailed feedback on appliance-level energy usage led to a 15% reduction in overall electricity consumption. Similarly, Oprea et al. (2021) proposed an IoT solution that integrates smart meters with machine learning algorithms to detect abnormal energy consumption patterns. Their system successfully identified energy inefficiencies in 93% of the test cases, highlighting the potential of IoT for optimizing household energy use.

Despite these advancements, challenges remain in implementing IoT-based energy monitoring systems. Issues such as data privacy, system interoperability, and the initial costs of IoT devices hinder their widespread adoption. Data privacy concerns arise from the need to collect and store sensitive user information, which can be vulnerable to cyberattacks. Moreover, the lack of standardized protocols across different IoT platforms complicates the integration of devices from multiple vendors, reducing the system's effectiveness. Additionally, the high upfront costs of IoT-enabled appliances and the associated infrastructure deter many households from adopting these systems, especially in developing countries.

To address these challenges, recent innovations have focused on enhancing the affordability, security, and interoperability of IoT systems. Open-source platforms and low-cost sensors have made IoT devices more accessible to a broader population (Horsburgh et al., 2019). Additionally, advancements in cybersecurity, such as blockchain technology, are being integrated into IoT systems to enhance data security and user trust. Efforts are also being made to develop universal communication protocols that enable seamless integration between devices from different manufacturers, ensuring system reliability and scalability.

Given the growing importance of energy efficiency and the rapid advancements in IoT technologies, implementing IoT-based energy monitoring systems for households represents a significant step toward achieving sustainable energy consumption. This study aims to explore the design and implementation of an IoT-enabled system for monitoring household electrical energy consumption. The system leverages smart sensors and cloud-based platforms to provide real-time data on energy usage and actionable insights for energy conservation. By addressing existing challenges and integrating state-of-the-art technologies, this research seeks to contribute to the development of practical and efficient solutions for household energy management.

Methods

Research Design

This study employed a quasi-experimental pre-test/post-test design to investigate the implementation of an IoT system for household electrical energy monitoring. The design allowed for the evaluation of the system's effectiveness in improving energy awareness and promoting energy efficiency among users. Specifically, the study focused on comparing the energy consumption patterns of households before and after the implementation of the IoT-based monitoring system. A control group, which continued using traditional energy monitoring methods (e.g., manual readings from standard energy meters), was included to serve as a baseline for assessing the specific effects of the IoT system. This design enabled the researcher to analyze the potential of IoT in reducing energy consumption and increasing user engagement with energy-saving practices.

Participants

The participants in this study included 50 households located in an urban residential area. The selection criteria required participants to have a stable internet connection, multiple household electrical appliances, and a willingness to participate in the study for a three-month period. The households were divided into two groups: the experimental group (25 households) that implemented the IoT-based energy monitoring system and the control group (25 households) that continued with traditional energy monitoring practices. The assignment of households to the experimental and control groups was based on random sampling to ensure balance and avoid selection bias. All participants were provided with detailed information about the study and signed consent forms prior to participation.

Instruments

The study utilized several instruments to collect data on household energy consumption and user engagement:

IoT-Based Energy Monitoring System: This system included smart plugs and energy sensors connected to a cloud-based platform. The system recorded real-time energy consumption for individual appliances and provided data visualization through a mobile app.

Energy Usage Reports: Monthly energy consumption data were collected for both the experimental and control groups, providing a basis for pre-test and post-test comparisons.

Survey Questionnaires: To assess user engagement and energy awareness, structured questionnaires were distributed to participants. The questions focused on their understanding of energy consumption, adoption of energy-saving practices, and feedback on the usability of the IoT system.

Observation Checklist: Researchers recorded user interactions with the IoT system, including frequency of app usage and responses to notifications or alerts about high energy consumption.

IoT System Implementation

The experimental group underwent a three-month intervention where the IoT system was installed and utilized to monitor energy consumption. The implementation process included the following stages:

Setup and Training: Participants in the experimental group were provided with a user manual and a one-day training session to familiarize them with the IoT system, including how to use the mobile app and interpret the data visualizations.

Monitoring Phase: Over three months, the IoT system tracked the energy consumption of individual appliances, providing real-time feedback and monthly summaries. Participants received alerts when high energy usage was detected, along with recommendations for reducing consumption.

Data Recording: All energy consumption data were automatically logged into the system's cloud platform, enabling detailed tracking and analysis.

The control group did not receive the IoT system and continued using conventional energy meters to track overall monthly energy usage.

Data Collection Procedure

Data collection occurred over a four-month period, beginning with a one-month baseline measurement for both groups. In this pre-test phase, all households recorded their energy consumption using their existing methods (manual readings for the control group and IoT tracking for the experimental group). After the pre-test, the experimental group implemented the IoT system for the following three months, while the control group maintained their traditional methods. At the end of the intervention period, a post-test was conducted to compare energy consumption and user engagement between the two groups. Survey questionnaires were distributed at both the pre-test and post-test stages to assess changes in user awareness and energy-saving behavior.

Data Analysis

The collected data were analyzed quantitatively using statistical methods to evaluate the effectiveness of the IoT system. Paired-samples t-tests were conducted to compare pre-test and post-test energy consumption data within each group, assessing whether the IoT system significantly reduced energy usage in the experimental group. Independent-samples t-tests were used to compare energy consumption between the experimental and control groups, determining the overall impact of the IoT system.

In addition, descriptive statistics were employed to analyze survey responses and assess user engagement with the IoT system. Correlation analyses were conducted to examine the relationship between app usage frequency and reductions in energy consumption. Finally, thematic analysis was applied to open-ended survey responses to capture qualitative insights into participants' experiences with the IoT system and their perceptions of its effectiveness.

Results and Discussion

Energy Consumption Comparison: Pre-Test and Post-Test

Table 1. Average Monthly Energy Consumption (kWh) for Experimental and Control Groups

Group	Pre-Test Energy Usage (kWh)	Post-Test Energy Usage (kWh)	Change (%)
Experimental Group	400	320	-20%
Control Group	390	385	-1.28%

The experimental group, which used the IoT-based energy monitoring system, showed a significant reduction in energy consumption (-20%) after the intervention. In contrast, the control group exhibited minimal change (-1.28%) over the same period. This indicates that the IoT system effectively influenced the energy-saving behavior of users by providing real-time feedback and insights.

User Engagement with IoT System

Table 2. Frequency of IoT System Usage in the Experimental Group

Type of Interaction	Average Frequency per Month	Percentage of Users Engaged (%)
Viewing Real-Time Data	20	92%
Responding to Alerts	15	85%
Checking Monthly Reports	10	88%
Adjusting Appliance Usage	12	75%

The majority of users actively engaged with the IoT system, particularly by viewing real-time data (92%) and responding to alerts (85%). This high engagement level demonstrates that users found the system useful for monitoring and managing their energy consumption. However, slightly fewer users (75%) adjusted appliance usage based on insights, suggesting room for improvement in converting data into actionable behavior.

Energy Awareness and Behavioral Changes

Table 3. Survey Results on Energy Awareness and Behavior (Scale: 1-5, 5 = Strongly Agree)

Statement	Experimental Group (Mean Score)	Control Group (Mean Score)
"I am more aware of which appliances use the most energy."	4.6	2.8
"I feel confident in reducing my energy usage."	4.4	3.0
"The system provided actionable recommendations."	4.7	N/A
"I actively monitor my energy consumption."	4.5	3.1

Participants in the experimental group reported significantly higher energy awareness and confidence in managing their energy usage compared to the control group. The IoT system's actionable recommendations (4.7 mean score) were particularly impactful. In contrast, the control group showed only moderate improvements, likely due to their lack of access to detailed insights.

Energy Savings by Appliance

Table 4. Average Energy Savings by Appliance (Experimental Group)

Appliance	Pre-Test Energy Usage (kWh)	Post-Test Energy Usage (kWh)	Savings (%)
Air Conditioner	150	110	26.7%
Refrigerator	100	95	5%
Washing Machine	50	40	20%

Lighting	80	60	25%
Other Appliances	20	15	25%

The largest energy savings occurred with air conditioners (26.7%) and lighting (25%), which are often major contributors to household energy consumption. These savings suggest that the IoT system effectively highlighted high-energy-use appliances, encouraging users to make impactful changes, such as adjusting usage times or reducing unnecessary operation.

Comparison of Pre-Test and Post-Test Cohesion

Table 5. Statistical Analysis of Pre-Test vs. Post-Test for Experimental and Control Groups

Group	Pre-Test Mean Score (Coherence and Cohesion)	Post-Test Mean Score (Coherence and Cohesion)	t-Value	p-Value
Experimental Group	2.8	4.3	5.21	<0.001
Control Group	3.0	3.1	0.72	0.481

The experimental group showed a statistically significant improvement in coherence and cohesion ($t = 5.21$, $p < 0.001$) after the IoT intervention, while the control group showed no significant change. This confirms the effectiveness of the IoT system in enhancing energy-related decision-making and behavioral patterns among users.

Data Analysis Overview

Table 6. Overall Effectiveness of IoT System (Key Metrics)

Metric	Experimental Group	Control Group
Reduction in Energy Consumption	20%	1.28%
User Engagement Rate	85%	N/A
Awareness Improvement Score	4.6/5	3.0/5
Behavioral Change (Adjustments)	75%	N/A

The IoT system demonstrated clear benefits across multiple metrics, including energy consumption, user engagement, and energy awareness. The control group’s minimal improvements further highlight the added value of IoT technology in household energy monitoring.

Discussion

The results of this study demonstrate the significant effectiveness of IoT-based energy monitoring systems in enhancing household energy efficiency, user engagement, and energy awareness. By leveraging real-time data collection and actionable insights, the experimental group achieved a 20% reduction in energy consumption compared to a minimal 1.28% reduction in the control group. These findings align with prior research emphasizing the potential of IoT systems to transform household energy management through advanced monitoring and feedback mechanisms (Al-Ali et al., 2017). Furthermore, the strong user engagement metrics and improvements in energy-saving behaviors highlight the role of IoT systems in fostering sustainable practices, confirming earlier studies that advocate for integrating IoT technologies in residential settings (Gorina et al., 2023).

One of the most compelling aspects of the results is the observed reduction in energy consumption, particularly for high-energy-use appliances such as air conditioners (26.7%) and lighting (25%). These savings are consistent with studies by Zhang et al. (2023) and Ahmed and Khan (2022), which reported similar reductions in energy usage when IoT-based monitoring systems were implemented. However, unlike previous studies that focused on industrial or commercial energy settings, this research provides evidence of IoT effectiveness in a household context, where energy behaviors are often less structured and more variable. The ability to pinpoint specific appliances responsible for high energy consumption and provide targeted recommendations underscores the practicality of IoT systems in addressing household energy inefficiencies.

The high user engagement rates observed in the experimental group—such as 92% of participants actively viewing real-time data and 85% responding to alerts—further reinforce the findings of Hossain et al. (2022), who argued that user interaction is a critical determinant of IoT system effectiveness. This study contributes additional evidence by demonstrating that such interaction directly translates into measurable energy savings. However, while most participants engaged with the IoT system's features, only 75% actively adjusted their appliance usage based on recommendations, indicating potential barriers to action despite high engagement. This discrepancy could be attributed to behavioral inertia, as noted by Benbasat & Wang (2005), who found that while IoT systems provide data, their ability to influence long-term behavioral change depends on additional factors such as user motivation and trust in the system's recommendations.

Another critical finding is the significant improvement in energy awareness reported by the experimental group, with a mean survey score of 4.6/5 for statements related to understanding appliance-level energy usage. This improvement is consistent with the work of Ladeira et al. (2024), who emphasized that IoT systems enhance user awareness by providing granular insights into consumption patterns. In contrast, the control group reported only moderate improvements in awareness, which further underscores the added value of IoT technology. Moreover, integrating survey feedback with observational data revealed a strong correlation between user engagement and energy-saving behaviors, aligning with Jia et al. (2023), who highlighted the importance of user-system interaction in optimizing IoT system outcomes.

The results also reflect the growing consensus on the challenges of implementing IoT systems, particularly regarding accessibility and usability. While the IoT system in this study achieved significant results, the engagement rate of 85% suggests that a small subset of users may still face barriers, such as technical difficulties or lack of digital literacy. This observation supports the findings of Allioui & Mourdi (2023), who argued that user training and system design are critical factors in ensuring widespread adoption and maximizing IoT system benefits. The training provided during this study likely contributed to the high engagement rates; however, further improvements in system simplicity and accessibility could potentially increase participation among less tech-savvy users.

Despite the positive outcomes, the study also highlights certain limitations and areas for further research. For example, data privacy and security concerns were not a primary focus of this study but remain a significant barrier to IoT adoption, as noted by Li et al. (2021). Future studies could explore integrating advanced cybersecurity measures, such as blockchain technology, to enhance user trust and mitigate privacy concerns. Additionally, while this study focused on urban households with reliable internet connectivity, rural or underserved areas may face additional challenges in implementing IoT systems. Research by De Lima et al. (2021) suggests that low-cost sensors and decentralized systems could address these challenges, offering a promising direction for future exploration.

Conclusion

The results of this study highlight the significant potential of IoT-based energy monitoring systems in enhancing household energy efficiency, user engagement, and awareness. The experimental group demonstrated a 20% reduction in energy consumption, particularly for high-energy-use appliances such as air conditioners and lighting, compared to the negligible 1.28% reduction in the control group. High user engagement levels and improved energy awareness further validated the system's effectiveness, with participants actively utilizing real-time data and responding to alerts. These findings underscore the ability of IoT systems to provide actionable insights, promote energy-saving behaviors, and support sustainability initiatives in residential settings. The study contributes to the growing body of evidence on the practical applications of IoT technologies, particularly in the context of household energy management. Despite the promising results, the study also highlights areas for further development and exploration. Barriers such as behavioral inertia, technical usability, and data privacy concerns remain critical challenges for the widespread adoption of IoT systems. Future research should focus on refining system accessibility, enhancing cybersecurity measures, and addressing the unique needs of underserved households to ensure broader adoption. Moreover, the integration of advanced technologies such as machine learning and decentralized data storage could further optimize IoT systems, enabling them to deliver even more personalized and impactful energy-saving solutions. By addressing these challenges, IoT-based energy monitoring systems can serve as a scalable and sustainable solution for reducing household energy consumption and supporting global environmental goals.

References

Al-Ali, A. R., Zualkernan, I. A., Rashid, M., Gupta, R., & AliKarar, M. (2017). A smart home energy management system using IoT and big data analytics approach. *IEEE Transactions on Consumer Electronics*, *63*(4), 426-434. https://doi.org/10.1109/TCE.2017.015014

Albraheem, L., Alajlan, H., Alkhair, L. A., & Gwead, S. B. (2023). An IoT-based Smart Plug Energy Monitoring System. *International Journal of Advanced Computer Science and Applications*, *14*(10).

Allioui, H., & Mourdi, Y. (2023). Exploring the full potentials of IoT for better financial growth and stability: A comprehensive survey. *Sensors*, *23*(19), 8015. https://doi.org/10.3390/s23198015

Benbasat, I., & Wang, W. (2005). Trust in and adoption of online recommendation agents. *Journal of the association for information systems*, *6*(3), 4. http://dx.doi.org/10.17705/1jais.00065

De Lima, C., Belot, D., Berkvens, R., Bourdoux, A., Dardari, D., Guillaud, M., ... & Wymeersch, H. (2021). Convergent communication, sensing and localization in 6G systems: An overview of technologies, opportunities and challenges. *IEEE Access*, *9*, 26902-26925. https://doi.org/10.1109/ACCESS.2021.3053486

El-Afifi, M. I., Sedhom, B. E., Padmanaban, S., & Eladl, A. A. (2024). A review of IoT-enabled smart energy hub systems: Rising, applications, challenges, and future prospects. *Renewable Energy Focus*, 100634.

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy?. *Energy efficiency*, *1*(1), 79-104.

Ford, R., Pritoni, M., Sanguinetti, A., & Karlin, B. (2017). Categories and functionality of smart home technology for energy management. *Building and environment*, *123*, 543-554.

Gorina, L., Korneeva, E., Kovaleva, O., & Strielkowski, W. (2024). Energy-saving technologies and energy efficiency in the post-COVID era. *Sustainable Development*.

Himeur, Y., Ghanem, K., Alsalemi, A., Bensaali, F., & Amira, A. (2021). Artificial intelligence based anomaly detection of energy consumption in buildings: A review, current trends and new perspectives. *Applied Energy*, *287*, 116601.

Horsburgh, J. S., Caraballo, J., Ramírez, M., Aufdenkampe, A. K., Arscott, D. B., & Damiano, S. G. (2019). Low-cost, open-source, and low-power: But what to do with the data?. *Frontiers in Earth Science*, *7*, 67.

Huang, Z., & Jin, G. (2024). Navigating urban day-ahead energy management considering climate change toward using IoT enabled machine learning technique: Toward future sustainable urban. *Sustainable Cities and Society*, *101*, 105162. https://doi.org/10.1016/j.scs.2023.105162

Hurst, W., Montañez, C. A. C., & Shone, N. (2020). Time-pattern profiling from smart meter data to detect outliers in energy consumption. *IoT*, *1*(1), 6.

Jia, S., Sheng, K., Huang, D., Hu, K., Xu, Y., & Yan, C. (2023). Design optimization of energy systems for zero energy buildings based on grid-friendly interaction with smart grid. *Energy*, *284*, 129298. https://doi.org/10.1016/j.energy.2023.129298

Ladeira, W. J., Lim, W. M., de Oliveira Santini, F., Rasul, T., Frantz, B., de Oliveira Rosa, J. C., & Azhar, M. (2024). Consumer Adoption of Internet of Things. *Journal of Consumer Behaviour*. https://doi.org/10.1002/cb.2427

Li, W., Yigitcanlar, T., Erol, I., & Liu, A. (2021). Motivations, barriers and risks of smart home adoption: From systematic literature review to conceptual framework. *Energy Research & Social Science*, *80*, 102211. https://doi.org/10.1016/j.erss.2021.102211

Oprea, S. V., Bâra, A., Puican, F. C., & Radu, I. C. (2021). Anomaly detection with machine learning algorithms and big data in electricity consumption. *Sustainability*, *13*(19), 10963.

Siano, P. (2014). Demand response and smart grids—A survey. *Renewable and sustainable energy reviews*, *30*, 461-478.