Internet of Things (IOT)-Based Smart Energy Monitoring and Management System

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Abstract
Rapid growth of electrical devices should be accompanied with monitoring and controlling electric energy consumption for more reliable operation. Conventional electric energy monitoring methods cannot reveal the whole story on current energy consumption levels; thus, it is hard for the users to identify if the energy consumption levels are too high. This research aims to develop an IoT based smart electric energy monitoring and management system to offer a real-time measure and monitoring on electric energy consumption. In the study, a PZEM-004T energy monitoring module is used to measure all electrical parameters, and the measuring data will be transferred from the ESP32 microcontroller chip via Wi-Fi to an IoT monitoring platform for visualization. The user is able to monitor, or observe voltage, current, power and energy consumption remotely, and a threshold-based excess consumption detection mechanism is designed for identifying abnormal energy consumption situation. Analysis based on the synthetic data with various load types is resulted to validate the monitoring and management function of the proposed system. The research mainly focuses on establishing the communication between electrical sensing module and IoT monitoring system, as well as the evaluation on proposed system for monitoring and managing the electric energy consumptions.

***Keywords**: Internet of Things, smart energy monitoring, energy management, ESP32, PZEM-004T, real-time monitoring.*

1.0. Introduction

The rising demand for energy and the need for energy efficiency have led to the emergence of a keen interest in smart technologies that facilitate energy monitoring and energy consumption control. Conventional energy monitoring technologies usually provide incomplete information about the process of energy consumption, thereby limiting users in their ability to notice cases of excessive energy usage and make necessary adjustments. The emergence of IoT technologies gives an opportunity to overcome this deficiency by linking sensing devices, communication technology, processing platform, and user interface to enable energy monitoring and management. IoT-based energy monitoring systems allow users to gather electrical parameters and access consumption data (Muralidhara et al., 2020; Ahmad et al., 2021). By applying an Internet of Things-based system of smart energy monitoring and control, the electric parameter (voltage, current, power, electricity energy consumption) of users could be monitor almost continuously. The data can be transferred to cloud platform/monitor through communication network, so that users could monitor the electric energy consumption process in real time. This system will give more comprehensive information about electric energy consumer and sort out the certain appliances or time when electric energy consumption is large (Zakaria & Ishak, 2022; Siva Balan et al.,

The smart monitoring of energy has also been identified in residential and smart home settings. Energy management solutions can combine IoT devices and monitoring and controlling functionalities in order to enhance electricity usage. They can offer information to the consumers regarding their consumption patterns and help them take actions which will lead to reduction of unnecessary energy usage (Aliero et al., 2021). In addition to this, there have been efforts to combine IoT and smart meters in order to be able to provide information about electricity consumption in a more sophisticated and timelier manner (Tahir et al., 2022). Wireless communication solutions such as NB-IoT and other IoT communication technologies have also been used in order to transfer energy monitoring data to remote systems (Siva Balan et al., 2023).

Finally, recent trends in the field of smart energy monitoring have proven that microcontrollers, sensors, cloud computing platforms, and web-based applications have been used. Smart energy monitoring systems which include devices like ESP32 and PZEM-004T can measure electrical parameters and transfer the acquired data (Pradhan et al., 2025). Another type of IoT-based smart energy meter system has been developed, which uses a web application in order to allow remote energy monitoring. These developments indicate that relatively affordable IoT components can be used to develop practical energy-monitoring solutions.

Despite these developments, there remains a need for simple and integrated energy monitoring systems that combine real-time measurement, remote data monitoring, and basic energy management functions in a practical implementation. Existing studies have explored different communication technologies, smart meters, cloud platforms, and management approaches, but implementations vary considerably in their architecture, functionality, and level of integration (Benhamaid et al., 2022; Ahmad et al., 2021). A system that combines real-time electrical measurement with IoT connectivity and a user-friendly monitoring platform can provide a practical approach to addressing this need.

Therefore, this study focuses on the development of an **IoT-Based Smart Energy Monitoring and Management System** for monitoring of electrical energy consumption. The proposed system is designed to measure relevant electrical parameters, transmit the collected data through an IoT-enabled platform, and present the information to users for effective monitoring and management. Synthetic energy-consumption data are used to evaluate the proposed monitoring and management functions and demonstrate how IoT technology can support accessible and timely energy-consumption information,

Existing studies therefore demonstrate significant interest in IoT-enabled energy monitoring and management. However, differences remain in the technologies, architectures, monitoring interfaces, and management functions employed by the systems. Some studies emphasize smart metering, while others focus on communication technologies, cloud platforms, control, security, or energy conservation (Ahmad et al., 2021; Joha, 2022). In addition, several implementations concentrate primarily on measurement and display without combining real-time monitoring with a simple management mechanism suitable for practical small-scale applications. This study addresses these limitations by proposing an IoT-based smart energy monitory and management system that integrates electrical measurement, remote monitoring, and a basic consumption – threshold mechanism.

2.0. Related Works

IoT has been used in energy monitoring and management due to its capability of linking sensors, communication means, computing infrastructure, and user interface. In the context of energy applications, IoT devices are capable of collecting electrical variables in real time and sending the data to an external platform for monitoring and analysis purposes. It is through this technique that users get more elaborate information regarding their electricity usage in comparison with traditional approaches that depend mainly on meter readings (Muralidhara et al., 2020). IoT application in energy management has consequently enabled the creation of smart solutions that facilitate monitoring, consumption awareness, and optimal use of energy.

Typical smart energy monitoring systems use sensors and meters that capture various data including voltage, current, power, and energy consumption values. The captured data is analyzed using a microcontroller and then transmitted via the communication network to the cloud or to the user interface. An example of a smart energy meter built to monitor energy consumption at the level of the device showed the role of the Internet of Things technology in the collection of information on energy consumption and providing this information to the user (Muralidhara et al., 2020). Another example includes the development of smart energy monitoring systems that capture electrical parameters and convey this information to users digitally (Zakaria & Ishak, 2022). The development of smart energy meters has also focused on improving the accessibility of energy information. Traditional meters may provide information about total consumption without giving users sufficient insight into when or where energy is being consumed. IoT-enabled meters address this limitation by enabling the collection and transmission of measurements at shorter intervals. This allows users to observe consumption patterns and identify changes in electricity usage (Tathe et al., 2025). Recent implementations have also demonstrated the use of IoT-based smart meters for real-time electrical power monitoring, showing the continuing development of connected energy-monitoring technologies (Abiyyu et al., 2026).

Communication technology is an important component of an IoT-based energy monitoring system because measured data must be transferred from the sensing device to the monitoring platform. Different communication technologies have been investigated for this purpose. For example, NB-IoT has been applied to smart energy monitoring together with cloud technologies, providing a communication mechanism for transmitting energy-related information to a remote platform (Siva Balan et al., 2023). Other research has examined LoRaWAN-based smart meters combined with the oneM2M platform for energy monitoring, demonstrating the application of low-power wide-area communication technologies in connected metering environments (*Energy monitoring using LoRaWAN-based smart meters and oneM2M platform*, 2021). Wireless communication is particularly useful where users need to access energy information remotely. An IoT-based smart energy meter can transmit measured data through a network connection and make the information accessible through a web application or other digital interface. Such systems can support both monitoring and control functions, allowing users to observe energy consumption without being physically present at the location of the meter (*A smart energy meter using IoT for monitoring and control energy via web application*, 2023). Web-based access can therefore improve the usability of energy monitoring systems by presenting electrical measurements in a form that can be accessed through connected devices.

Effective energy management is more than just the measurement of electricity usage. It entails making good use of data collected in order to make good decisions regarding energy usage. For example, IoT-based energy management systems have been researched in smart home settings in order to monitor energy consumption and undertake energy saving activities. This kind of systems may integrate connected devices, communication and management to enhance energy usage efficiency (Aliero et al., 2021). The use of IoT technology in energy management is also pertinent to the concept of Green-IoT technology in which energy efficiency and lower energy consumption become major factors. Cloud platforms have allowed smart energy monitoring systems to gain even more capabilities. It is possible for cloud platforms to provide an independent platform where energy data will be received, stored, and presented. The combination of NB-IoT and cloud technology in smart energy monitoring systems shows how energy data can be transferred to remote computing facilities from the monitoring devices (Siva Balan et al., 2023). The cloud connected systems can also help in storing historical data. This can be useful in comparing energy consumption at different times. Some other technologies have also been investigated by certain researchers in order to enhance the security and management of smart energy systems. The integration of IoT and blockchain has been done in smart energy meters in order to facilitate energy saving and create a network for energy monitoring (Tahir et al., 2022). Despite the fact that the utilization of blockchain provides further capabilities, the integration of blockchain makes the system more complex than the basic IoT system. For small-scale energy monitoring systems, an IoT-based system may work well enough. Another aspect related to smart energy monitoring systems that is worth considering is their hardware. New approaches suggest using a combination of microcontrollers, like ESP32, along with electrical measurement modules, such as PZEM-004T. This can be helpful to cover all the necessary functionalities needed for an IoT-based monitoring system (Pradhan et al., 2025). With the help of accessible hardware, it becomes possible to create working systems able to measure electrical parameters and transmit information about them.

The energy metering system may have an alert component as well, which will help in identifying unusual or higher consumption levels. The alert is created when the consumption value goes beyond the set limit, and then the user can react to the rise in the consumption level. It has been seen that IoT-based smart meters having alert components have provided the ability to inform users through communication technology regarding any activity related to energy (Vedhathiri, 2025). There have been further developments in terms of designing and implementing IoT-based smart energy meters, with recent research concentrating on real-time monitoring, automated billing, and increased availability of information about consumption. A smart energy meter which was designed to offer real-time monitoring and automated billing is an example of how IoT technology may be developed and used for more services than mere measurements (Tathe et al., 2025). Other recent research has also concentrated on IoT-based energy monitoring systems for gathering and displaying information about electrical consumption (Sonar et al., 2026).

Other studies have been carried out on how smart energy meters based on the Internet of Things (IoT) have been designed and implemented in terms of power measurement and power quality analysis. This shows the significance of electrical measurement accuracy that is the base of energy measurement (Design, power quality analysis, and implementation of smart energy meter using Internet of Things, 2021). Measurement accuracy is essential since erroneous measurements of voltage, current, power, or energy will impact data presentation to end-users.

Energy monitoring in IoT can be undertaken at various levels. Some of these involve monitoring energy used by specific devices, while others involve energy management at a household level or even within smart energy systems (Muralidhara et al., 2020; Aliero et al., 2021). Device-level monitoring can reveal what device consumes the most energy, while household-level monitoring reveals overall consumption of electricity. It all boils down to who is the target audience of the monitoring exercise. Existing studies therefore demonstrate significant interest in IoT-enabled energy monitoring and management. However, differences remain in the technologies, architectures, monitoring interfaces, and management functions employed by the systems. Some studies emphasize smart metering, while others focus on communication technologies, cloud platforms, control, security, or energy conservation (Ahmad et al., 2021; Joha, 2022). In addition, several implementations concentrate primarily on measurement and display without combining real-time monitoring with a simple management mechanism suitable for practical small-scale applications. The gap addressed by this study is the development of a relatively simple and integrated IoT-based system that combines real-time electrical energy measurement, IoT data transmission, accessible monitoring, and evaluation of its effectiveness for energy monitoring and management. The proposed system is designed to support real-time energy monitoring, while synthetic energy-consumption data are used to evaluate its monitoring and management functions.

3.0. Methodology

This study adopted a practical system development approach to design and evaluate an IoT-based smart energy monitoring and management system. The methodology focused on the design of a system capable of measuring electrical energy consumption, processing energy-related information, transmitting data through an IoT communication platform, and providing users with accessible information for monitoring and management.

The methodology was organized around system requirements, hardware and software components, system architecture, system development, synthetic data generation, and performance evaluation. Synthetic energy-consumption data were used for the evaluation of the proposed system to represent electrical measurements that could be obtained from connected loads under different operating conditions.

3.1. System Requirements

The system that has proposed use hardware and software to provide the solution for electrical measurement, data handling, communication, monitoring and management. There are, main hardware parts used in this system are an embedded microcontroller ESP32, PZEM-004T energy measurement component, electrical load, power supply, and wire connection. The main hardware part is ESP32 which has the application for measurement, processing, managing and access to other related units. In contrast, the PZEM-004T is used to measuring electrical parameters; voltage, current, power and energy from the load.

3.2. Software Development

The software controls data processing, wireless transmission, and monitoring. The ESP32 processes energy measurements and transmits the information through Wi-Fi to the IoT monitoring platform, where voltage, current, power, and energy consumption are displayed. Synthetic energy-consumption data are used for the system evaluation.

3.3. Energy Consumption Monitoring

The provided data system indicates and measures 4 main electric parameters. They are voltage, current, power and accumulated energy. The voltage corresponds to the electrical potential at the load, the current corresponds to the flow of the electrical charge, the power corresponds to the

extent of the electrical energy for a particular time and accumulated energy are the historical consumption.
The relationship between voltage, current, and power can be represented as:
$P = V \times I$
Where:
P = electrical power in watts (W)
V = voltage in volts (V)
I = current in amperes (A)
Energy consumption can subsequently be monitored over time and expressed in kilowatt-hours (kWh). This measurement provides the basis for observing changes in consumption and assessing the operation of the proposed monitoring system.

3.4. Data Generation Procedure

Synthetic energy-consumption data were generated to represent measurements from different electrical load conditions. The dataset includes voltage, current, power, and energy-consumption values recorded at predetermined time intervals. The data were organized by monitoring period and used to analyze energy-consumption patterns and evaluate the proposed system.
The proposed system was evaluated using synthetic energy-consumption data. The evaluation focused on the system's ability to represent voltage, current, power, and energy consumption under different load conditions.
The generated data were analyzed using a graph to examine energy-consumption patterns and demonstrate the monitoring and management functions of the proposed system.

4.0. System Design and Implementation

The proposed system combines the PZEM-004T, ESP32, Wi-Fi communication, electrical load, and IoT monitoring platform. The design supports the measurement, processing, transmission, and monitoring of energy-consumption information.

4.1. System Design

The proposed system requires an ESP32 microcontroller, PZEM-004T energy monitoring module, electrical load, power supply, connecting wires, and an IoT monitoring platform. The ESP32 handles data processing and Wi-Fi communication, while the PZEM-004T provides electrical measurements such as voltage, current, power, and energy consumption. The software environment supports data processing, transmission, and monitoring. Synthetic energy-consumption data are used for system evaluation to simulate the measurements generated by the monitoring device.

4.2. System Architecture

The architecture proposed is comprised of five stages: energy measuring, data processing, communication, monitoring, and management. The electrical load is hooked up to a PZEM-004T energy meter that measures the electricity the architecture proposed is comprised of five stages: energy measuring, data processing, communication, monitoring, and management. The electrical load is hooked up to a PZEM-004T energy meter that measures the electricity consumption, voltage, current, power and energy flow. The ESP32 reads the values and transmits it to the IoT monitoring platform via Wi-Fi. The data is stored and displayed through the web/mobile user interface. Consumption, voltage, current, power and energy flow. The ESP32 reads the values and transmits it to the IoT monitoring platform via Wi-Fi. The data is stored and displayed through the web/mobile user interface. A management mechanism compares energy consumption with predefined thresholds to identify excessive usage and trigger alerts or energy-saving recommendations. The synthetic energy-consumption dataset is used for evaluation and analysis, while the alert mechanism provides notifications when consumption exceeds the defined threshold.

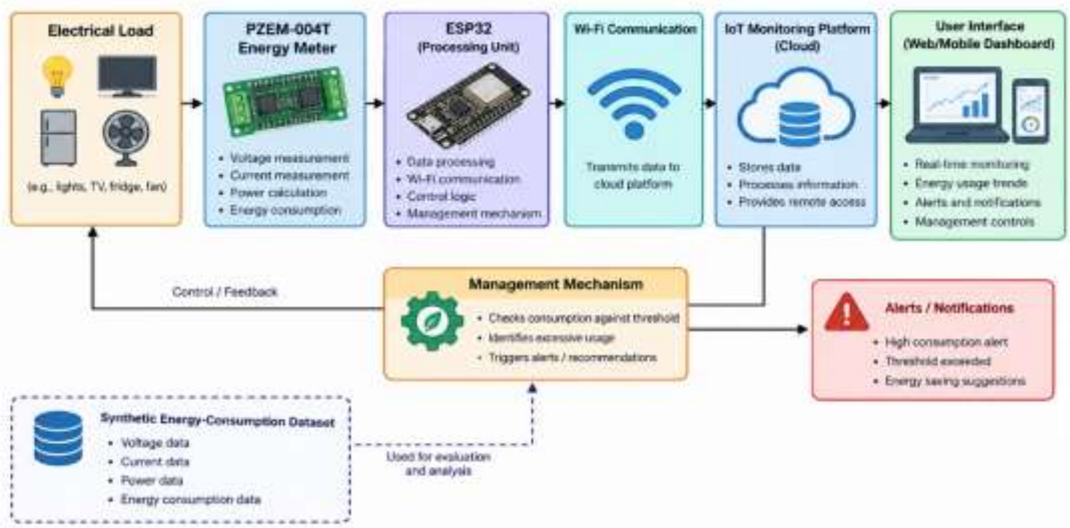

Figure 1: Proposed System Architecture

4.3. System Implementation

The proposed system is structured to receive energy-related data through the ESP32 and transmit the information to the monitoring platform. Synthetic data are used to evaluate the monitoring and management functions of the proposed system.

4.4. System Operation

The proposed system is designed to receive electrical measurements from the PZEM-004T through the ESP32 and transmits the information is transmitted through Wi-Fi to the IoT monitoring platform. The platform displays the energy information for user monitoring. Synthetic data are used to evaluate the monitoring and management functions.

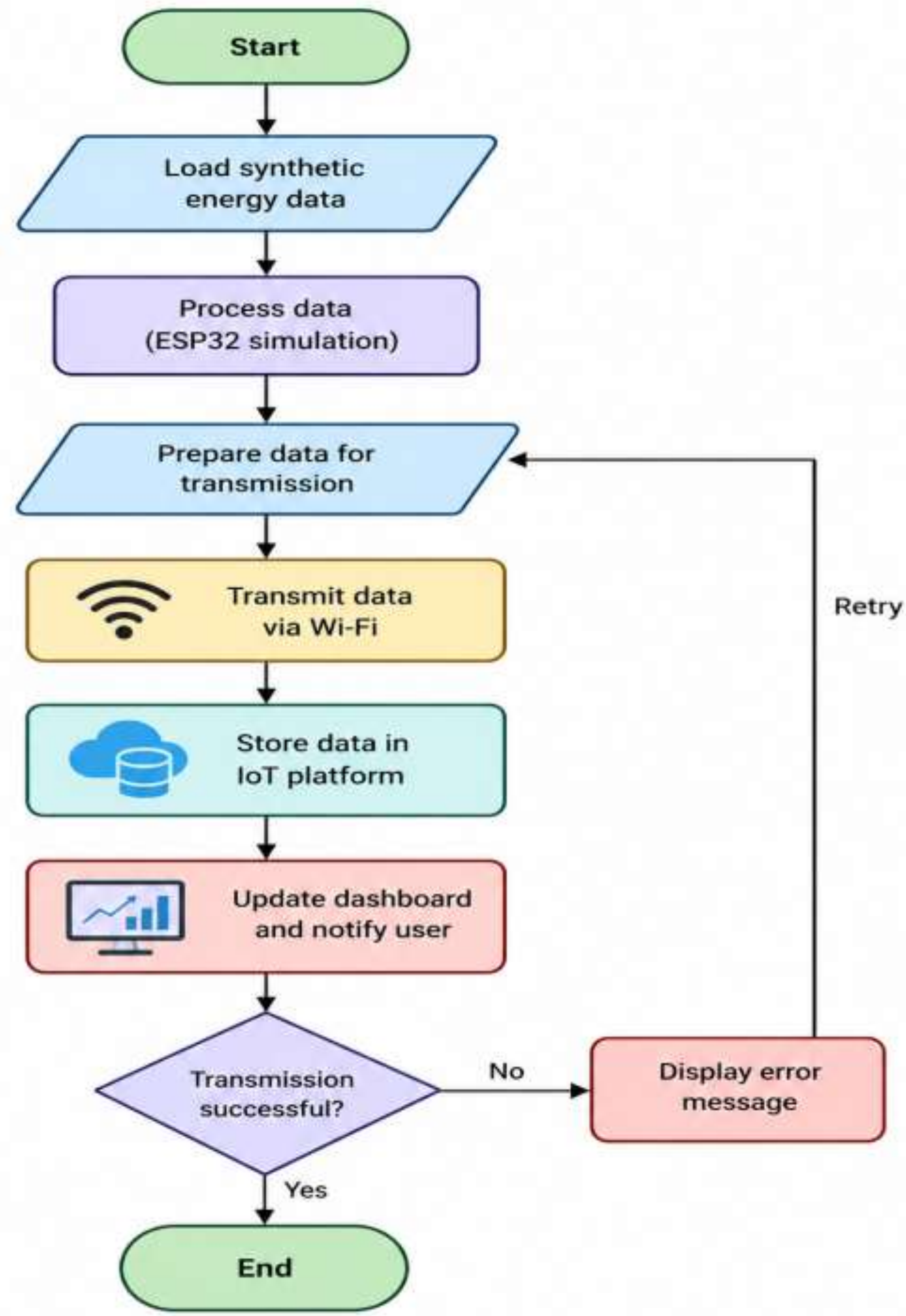

Figure 2: System Flowchart

5.0. Results and Discussion

Results

The proposed IoT-based smart energy monitoring and management system was evaluated using synthetic energy-consumption data representing different electrical load conditions. The generated dataset included voltage, current, power, and energy-consumption values over a defined monitoring period. The synthetic data were used to represent the type of electrical measurements expected from the proposed energy monitoring system under varying load conditions. The results were analyzed using a graphical representation of energy consumption over time to examine changes in consumption patterns and identify periods of relatively higher and lower energy usage. The analysis provides an indication of the monitoring and management functions of the proposed system.

5.1. Energy Consumption Analysis

A synthetic set of data was evaluated according to voltage, current, power and energy over time. The data is a representation of the change of energy consumption over a range of load conditions that include Lighting, Computer, Air Conditioner and Refrigerator.

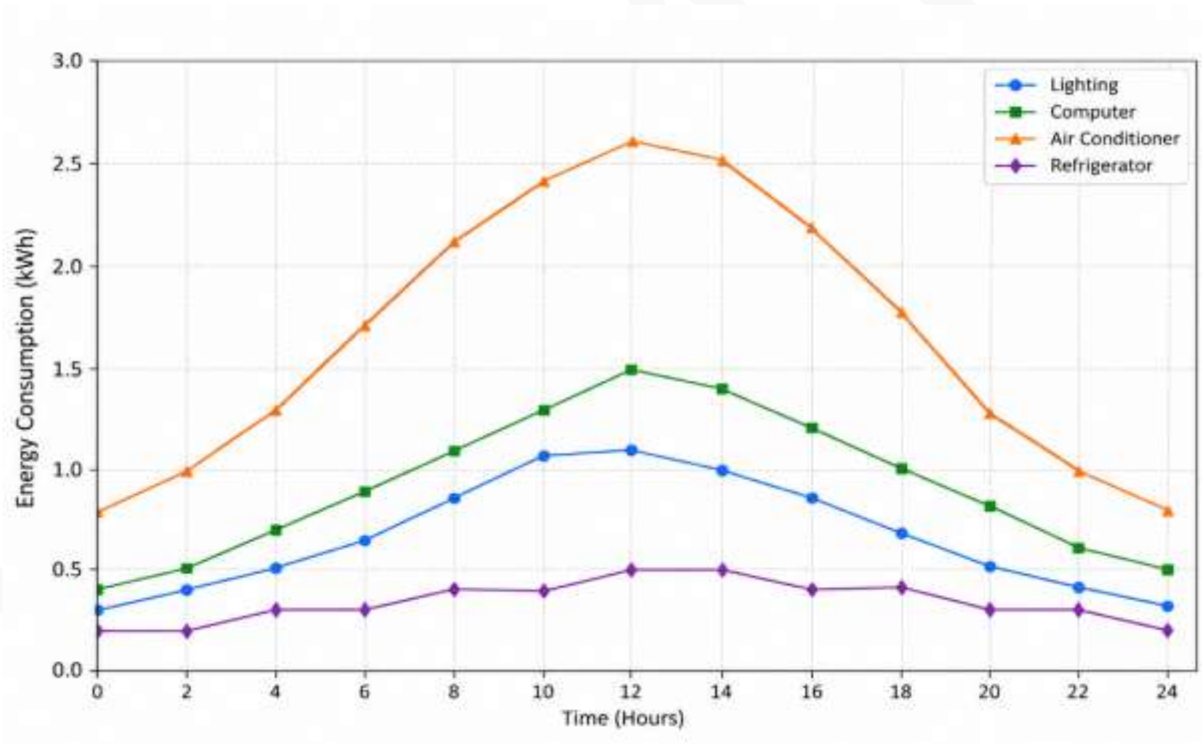

Figure 3: Energy Consumption Over Time

The graph illustrates changes in energy consumption during the monitoring period and provides a basis for identifying periods of relatively higher or lower consumption.

5.2. System Effectiveness

The results demonstrate that the proposed system provides a framework for monitoring energy-consumption using a predefined threshold.

The use of synthetic data provides an initial evaluation of the system's monitoring and management functions.

5.3. Discussion

The proposed system combines energy measurement, data processing, wireless communication, and remote monitoring within a single architecture. The results from the synthetic dataset illustrate how energy-consumption patterns can be examined under different load conditions. The analysis of voltage, current, power, and energy consumption provides useful information for identifying variations in energy usage and supporting basic energy-management decisions. The findings also indicate that the proposed IoT-based approach can provide a practical framework for monitoring energy consumption and making relevant energy information accessible to users.

6.0. Conclusion and Recommendations

The paper proposed an IoT based smart energy monitoring and management system using PZEM 004T, ESP 32, Wi-Fi-communication, and IoT monitoring platform. Synthetic energy-consumption data generated to investigate behaviors of voltage, current, power, and energy-consumption for various load conditions. The proposed energy monitoring system is practical for remote energy monitoring and detecting energetically high consumption relatively. The proposed system comprising energy measurement, IoT communication, remote monitoring, and proposed simple management mechanism can be a simple approach to support energy-monitoring and management activities.

6.1. Recommendations

Based on the proposed system, the following recommendations are made:
1. The system can be extended to support multiple electrical loads for more detailed device-level energy monitoring.
2. A mobile application can be incorporated to provide users with convenient access to energy-consumption information and alerts.
3.Future studies can collect longer-term energy-consumption data to support more detailed analysis of consumption patterns and energy-management behavior.

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