*Smart IoT Energy Management System for Home Use*

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*Abstract*—This project develops a Smart IoT Energy Management System (SIEMS) designed to empower homeowners to monitor and manage their energy usage in real-time. Utilizing an ESP32 microcontroller, an array of sensors, and a mobile application interface, SIEMS tracks energy consumption across various household appliances. By providing real-time data insights, the system enables users to make informed decisions and adjust their behavior, leading to reduced energy costs and a smaller environmental footprint. The project focuses on creating an accessible, user-friendly platform that simplifies energy monitoring while encouraging sustainable consumption practices. Ultimately, SIEMS aims to foster a culture of proactive energy management in households, contributing to broader sustainability goals.

Keywords—IoT, Energy Management, Smart Home, ESP32, Real-time Monitoring, Energy Consumption, Sustainable Practices, Mobile Application, Sensors, Cost Reduction, User Engagement, Cloud Integration

# Introduction

Global energy consumption has surged in recent years, driven by increased reliance on electronic devices and the growing number of energy-dependent households. The rise in energy demand poses significant challenges, including higher utility bills and environmental degradation. Despite these rising energy demands, many households lack effective tools to monitor or optimize their energy usage. Traditional energy management approaches are often reactive, leading to inefficiencies and wasted resources.

The Smart IoT Energy Management System (SIEMS) addresses this gap by providing a user-friendly, IoT-based solution for real-time energy monitoring and management. SIEMS enables homeowners to take charge of their energy consumption, making informed adjustments based on actionable insights. The system aligns with global sustainability goals, promoting responsible energy consumption that minimizes waste and reduces carbon emissions. By integrating advanced technology into everyday home management, SIEMS empowers users to contribute to a more sustainable future while enjoying financial savings.

SIEMS sets itself apart by addressing long-term engagement and user empowerment through an educational component and customizable user alerts. The system prioritizes sustainable behavior change, equipping users with tools and knowledge to manage energy more effectively over time. By tailoring its approach, SIEMS aims to increase lasting user engagement beyond typical short-term monitoring solutions.

# Background and related work

In 2018, the buildings sector—which includes both residential and commercial buildings—accounted for 20% of global energy consumption [1]. According to projections from the U.S. Energy Information Administration’s (EIA) *International Energy Outlook 2019* report, energy demand in buildings worldwide is expected to grow at an average annual rate of 1.3% from 2018 to 2050. This growth rate is particularly pronounced in non-OECD (Organization for Economic Cooperation and Development) countries, where building energy consumption is projected to increase by over 2% per year, approximately five times faster than in OECD nations.

Several IoT-based energy monitoring solutions have emerged to meet this need. For instance, one study presented a smart energy monitoring system utilizing the ESP32 microcontroller, providing users with real-time consumption data via WhatsApp notifications [2]. This system enhanced user engagement and proactive energy management, demonstrating that users who received real-time alerts on energy usage could reduce their consumption by up to 15%. However, the study did not explore long-term engagement strategies or additional features that could further optimize energy use, highlighting an opportunity for improvement in SIEMS.

Another study employed ThingSpeak as a cloud platform for data storage and analysis, integrating voltage and current sensors with an ESP32 microcontroller [3]. Their project allowed users to monitor energy usage through a mobile application, contributing to an average 10% reduction in household energy consumption. While effective, this system lacked customization options for user alerts and thresholds, which could enhance user experience and engagement.

The last study we examined implemented a mobile app interface to track individual appliance usage and set custom thresholds for alerts [4]. This granularity enabled users to identify high-consumption appliances and adjust usage accordingly, significantly impacting their monthly utility bills. However, their project did not emphasize user education or strategies to ensure sustainable behavior change, which SIEMS aims to address by incorporating educational resources and user-friendly features.

# Objectives

The primary objectives of the SIEMS project are to:

* **Provide Real-Time Energy Monitoring:** Track electricity usage on a per-appliance basis to offer precise, actionable data that empowers users to make informed energy choices. By integrating multiple sensors, SIEMS will provide granular data that allows users to see exactly where their energy is being consumed.
* **Reduce Costs through Data-Driven Insights:** Deliver alerts when usage exceeds predefined thresholds, encouraging cost-conscious behavior and helping users avoid waste. The system will analyze consumption patterns and provide tailored recommendations for reducing energy usage.
* **Increase User Awareness and Behavioral Engagement:** With access to trends and historical data, users can better understand and manage their household energy patterns. The project will also provide educational resources and tips on energy efficiency, fostering a culture of sustainable practices.
* **Enable Remote Control and Convenience:** Through a mobile interface or web interface, users will have direct access to their consumption data and the ability to remotely monitor and adjust energy usage in real-time. This feature enhances convenience and encourages users to engage actively with their energy management.
* **Educational Resources on Energy Efficiency**: SIEMS will include a dedicated educational component with tips on energy-saving, appliance efficiency ratings, and best practices. These resources will be delivered through the mobile app via push notifications, interactive articles, and in-app tips to encourage sustainable practices over the long term.

# System Design

The SIEMS design combines robust hardware with a flexible software solution to deliver accessible energy management.

## Hardware Components

### ESP32 Microcontroller: This efficient and low-cost microcontroller serves as the system’s core, handling sensor data processing and enabling Wi-Fi-based communication. Its dual-core processor and power-saving features make it ideal for a long-term, energy-efficient monitoring system, ensuring reliability and performance.

### Sensors: The following sensors will be integrated:

#### Voltage and Current Sensors (Voltage Detection Module): These sensors provide real-time measurements of power consumption for accurate energy usage calculations across different appliances, enabling users to track their energy consumption effectively.

#### PIR Motion Sensor: This sensor detects occupancy in rooms, allowing the system to optimize energy use by automatically turning off appliances in unoccupied areas. This feature not only saves energy but also enhances user convenience.

#### Temperature Sensor (DHT11 or Linear Temperature Sensor): Monitoring environmental conditions allows the system to manage HVAC (heating, ventilation, and air conditioning) systems more effectively, reducing unnecessary energy consumption by adjusting settings based on real-time data.

## Relay Modules (Single Relays)

These modules control high-power devices. Through automated on/off commands from the ESP32, the system can deactivate devices during inactive periods or upon reaching set thresholds, enhancing overall energy efficiency and reducing user intervention.

Hardware Architecture


Fig 1: Hardware Component System Architecture Diagram

## Software Components

### Mobile Application or Web Application Interface: Using the Blynk IoT platform, the application will serve as the primary user interface. Users will be able to view real-time data, set consumption thresholds, receive alerts, and remotely control connected appliances. The app’s user-friendly design ensures accessibility for users of varying technical backgrounds and includes interactive tutorials for better engagement.

### Data Processing and Cloud Integration: Energy data collected by the ESP32 will be periodically uploaded to the cloud, where users can access historical data, usage trends, and consumption breakdowns by appliance. This cloud integration facilitates easy access to insights and enhances user experience by allowing remote monitoring from any location.

### Data Privacy and Security: SIEMS will prioritize secure data handling by implementing encryption for data transmission, user authentication protocols, and privacy settings within the mobile app. This ensures that users’ energy data remains private and secure.

### Alert System: Notifications will be sent to the user’s mobile device if any appliance exceeds the user-defined energy threshold, supporting proactive energy management by alerting users to high-consumption patterns. The system will also include recommendations for actions users can take to reduce consumption based on their usage patterns.

### User Experience (UX) Considerations: The mobile app is designed for non-technical users, featuring an intuitive interface, accessibility features, and an onboarding tutorial to help users quickly familiarize themselves with energy management and system functions.

# Expected Outcomes

The SIEMS project is expected to yield the following outcomes:

* **Enhanced Energy Awareness:** By providing users with detailed, real-time insights into their energy consumption, SIEMS will promote cost-effective and environmentally responsible energy behaviors. Users will gain a deeper understanding of their consumption patterns, enabling them to make informed decisions.
* **Reduction in Household Energy Costs:** With data-driven insights, users can optimize their energy usage, aiming for a reduction of 10-20% in overall electricity bills by identifying and managing high-consumption appliances. The expected savings will be a compelling incentive for users to engage with the system.
* **Support for Sustainable Energy Practices:** The system will contribute to broader sustainability goals by helping users reduce household energy consumption and carbon footprint through informed energy use. By encouraging users to adopt sustainable practices, SIEMS aims to foster long-term behavioral change and awareness.
* **User Engagement and Education:** By providing educational resources and engaging features, the project aims to create a community of informed users committed to sustainable energy management.
* **Impact of Environmental Conditions**: SIEMS will consider factors such as fluctuating temperatures or humidity levels in energy monitoring. This adaptability ensures accurate usage tracking and assists users in managing appliance efficiency effectively in varied environments.

# Conclusion

The Smart IoT Energy Management System (SIEMS) offers a practical, IoT-based solution for household energy monitoring and management. By providing real-time, actionable insights, SIEMS can empower users to make informed decisions, thereby reducing energy costs and supporting sustainability. The system’s focus on accessibility, user engagement, and education makes it a valuable tool for households seeking to optimize their energy consumption and contribute to environmental conservation efforts. This project has the potential to serve as a scalable and adaptable solution for energy management, laying the groundwork for broader adoption of energy-efficient practices in residential settings. Through innovative technology and a commitment to sustainability, SIEMS aims to enhance the quality of life for users while fostering a more sustainable future. Moving forward, SIEMS can evolve by integrating with smart grids, employing machine learning for predictive analysis of usage patterns, and adapting its framework for commercial energy management applications. Such advancements would allow SIEMS to broaden its impact on sustainable energy practices.

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