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SMART HOME ENEGRY MANAGEMENT SYSTEM USING INTERNET-OF-THINGS

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Abstract-

Energy: A big problem worldwide Everybody is very interested in energy. We waste a lot of electricity due to our carelessness since we usually forget to turn off lights, fans, and such other devices. The goal of this Smart Energy Management System (SEMS) is to find the sources of energy waste in a homes and home-like environments. It measures ambient temperature and light intensity to monitor conditions and control devices. The control system as control [40] module is an Arduino microcontroller.

Light Intensity is measured using LDR (Light Dependent Resistor) and temperature is measured using an LM35 sensor. The light will turn on automatically when the light is insufficient and It will turn off automatically when the light is sufficient. Also, the fan is activated when the temperature exceeds 30°C and deactivated when it drops below this value. Also included is an energy consumption monitoring and power cut-off relay if the energy consumption is greater than a predetermined level. A buzzer is activated to inform the consumers that too much energy is consumed.

Keywords:
Smart Energy Management, Internet of Things, ESP32, Automation, Energy Efficiency, IoT, Renewable Integration

1 INTRODUCTION

Global final energy use has experienced tremendous growth over the past several decades, fueled mainly by population increase, the increase in urban population and use of electrical appliances in the residential sector. According to figures from the International Energy Agency, residential buildings account for about 27% of global electricity consumption, much of which is the result of ineffective usage behaviours. Tendencies like leaving the lights, or the fans or the other electrical equipments switched on even when they are not being used, result in huge energy wastage that not only increases the expenses but also result in higher carbon footprint through emission of carbons in larger amount.

The traditional energy management systems are manually observed and commanded, and they cannot solve the above mentions inefficiencies very good, because they are not accurate and can not be automated very easily. The advent of the Internet of Things (IoT) has provided a platform for SHEMS, in the form of sensor-microcontroller-cloud integration for the real-time monitoring, control, and scheduling of electrical consumption.

The need of saving electricity in the households leads to this work with a hope of sustainability and bill saving inferring. The existing systems are received to be, at least in some respect, deficient in that they do not provide instantaneous feedback, are not suitable for modern appliances, and do not include user interfaces for informing the users with actionable information. These limitations restrict the end–users for making smart decisions of slave smart energy use. In addition, Flexible systems are necessary for the integration of smart grid technology and renewable energy depending on energy need and environmental conditions.

Cheap hardware, intelligent algorithms, and friendly interfaces integrated into a SHEMS can assist in overcoming them and will allow the users to achieve energy-efficient living without compromising their living standard. In this paper SHEMS targeting energy monitoring, control and optimisation for residential households is proposed. It is based on an ESP32 microcontroller, connected to a set of sensors, such as a LDR for light intensity, a temperature sensor (LM35) and a current sensor (ACS712) for energy monitoring. Such devices make it possible to control appliances (relying on fixed thresholds to turn on and off in the particular case of lights, and on the temperature being more than 30°C for the fan).

A relay module that controls high power loads and buzzer that warns the user when power usage reaches limit. An LCD also shows on-demand data and an android app retrieves real-time data and communicates with the cloud using the cloud services Thing Speak and Firebase, allowing data to be read anywhere in the world. The system aims to achieve a minimum of 15% energy saver, and it will lead to both economic and environmental gains..

2 LITERATURE REVIEW

With the global shift toward sustainable energy and the rapid adoption of smart technologies, Smart Home Energy Management Systems (SHEMS) have garnered significant research attention. A variety of approaches have been explored to optimize household energy consumption, ranging from load scheduling to intelligent automation using IoT and AI technologies. This section presents an overview of relevant literature that underpins the design and development of the SHEMS discussed in this paper.

1. Dynamic Load Management Using Smart Devices

Kee Meng et al. (2017) proposed a dynamic control framework for managing the aggregated load of air conditioners [1] to mitigate peak demand on power grids. Their system emphasized load shifting using real-time control and scheduling algorithms. While effective in demand response management, the approach primarily focused on large-scale grid interaction rather than localized home-level automation.

2. Smart-Grid Transmission Coordination

Xin Wang et al. (2016) investigated transmission coordination mechanisms within smart grids. Their work proposed centralized control for energy flow optimization across smart infrastructures [2]. Although their contribution lies in grid-level energy balancing, it lacks direct applicability to decentralized, microcontroller-based systems like SHEMS, which target individual household optimization.

3. Cyber-Physical Systems and Game Theory for Energy Management

Neeraj Kumar et al. (2016) introduced a cyber-physical system (CPS) model based on game theory for managing energy usage in smart grids. Their model included multiple stakeholders and dynamic pricing models. However, such high-level frameworks require significant computational resources, making them less suitable for low-cost microcontroller environments used in residential settings.

4. Neural Network-Based Demand Estimation

Bharat Kumar et al. (2017) developed a demand estimator for microgrids using neural networks [5]. Their approach predicted consumption patterns with high accuracy, providing a strong foundation for intelligent energy automation. Despite its robustness, the computational complexity poses integration challenges with lightweight embedded systems like the ESP32 used in SHEMS.

5. Bluetooth Low Energy (BLE) for Home Automation

Mario Collotta et al. (2017) presented a BLE-based architecture for home energy control [6], highlighting the potential for localized control using energy-efficient communication protocols. Their work aligns closely with the goals of SHEMS in offering low-power solutions. However, BLE-based systems may face limitations in cloud integration and long-range communication, which are addressed in SHEMS through Wi-Fi and cloud platforms like Firebase and ThingSpeak.

6. Gaps in Existing Literature

While several studies focus on energy optimization and smart grid integration, most lack the combination of user-centric design, lightweight microcontroller implementation, cloud analytics, and real-time automation found in SHEMS. Few systems offer a comprehensive solution combining local sensor-based control, remote access via mobile apps, and real-time monitoring with analytics dashboards.

3 CASE STUDY

In everyday situations, we often forget to turn off lights, fans, and other household appliances when they are not needed, which results in unnecessary power consumption and higher electricity costs. Smart home energy management systems offer an effective solution to address this issue by automating device control based on environmental conditions.

For instance, in this system, a fan is programmed to automatically turn on when the room temperature exceeds 30°C and turn off when it drops below 30°C, thereby ensuring optimal comfort while minimizing energy usage. Similarly, lights are controlled based on ambient light levels to prevent wastage.

In this section, we demonstrate how the proposed Home Energy Management System can be applied to design an efficient, IoT-based control mechanism for lighting and temperature regulation in residential environments

4 OBJECTIVES

1. Monitor Real-Time Energy Usage

Continuously track the power consumption of home appliances using voltage and current sensors to provide accurate, real-time data.

2. Automate Appliance Control

Enable automatic switching of devices (like fans and lights) based on sensor inputs—e.g., turning on a fan when temperature exceeds 30°C and off when it falls below.

3. Optimize Energy Efficiency

Reduce unnecessary energy consumption by ensuring appliances operate only when needed, helping to lower electricity bills.

4. Provide Remote Monitoring and Control

Allow users to view and manage their home's energy usage remotely through a mobile app or web interface connected via Firebase.

5. Improve User Awareness

Offer detailed feedback and visualizations (using platforms like Thing Speak) to help users understand their energy habits and make informed decisions.

6. Enhance Safety with Alerts

Trigger alerts via buzzer or notifications when energy usage exceeds a predefined safe threshold to prevent overloads.

5 PROPOSED ARCHITECTURE

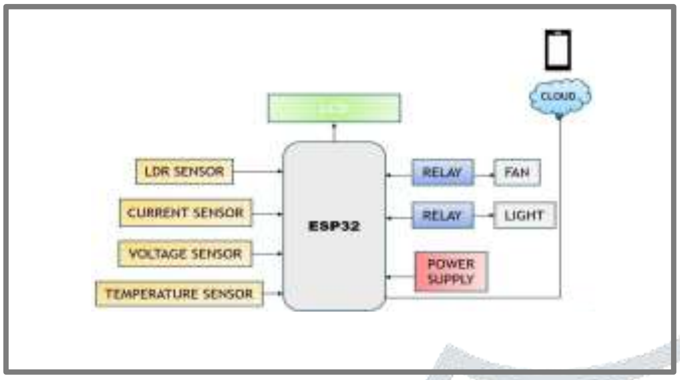


Figure 1: Smart Home Energy Management System Architecture

The Smart Home Energy Management System (SHEMS) is designed to optimize residential energy usage through intelligent automation. At its core, the ESP32 microcontroller with Wi-Fi and Bluetooth acts as the system's brain, handling data processing, device communication, and control.

- The system integrates a network of sensors:
- Temperature sensors adjust HVAC devices.
- LDR sensors manage lighting based on ambient light.
- Voltage and current sensors (ACS712) monitor energy usage in real time.

Android is used for user interface where appliances are monitored, controlled and scheduled to work from anywhere. Local feedback of energy consumption and system status is given through an LCD display.

Appliances such as fans and lights are driven by relay modules, which are activated based on the environment or the user-defined profiles. The stability of the power source guarantees that the system will continue to operate.

Data storage, remote access, and usage profiling is performed via Firebase and Thing Speak for cloud support. Through monitoring sensors and user preferences, the onboard control algorithms analyze data and optimize for efficiency and waste reduction, giving users actionable feedback and automatic control.

5.1 METHODOLOGY

ESP-32 MICRO - CONTROLLER

The ESP32 is a very inexpensive System on Chip (SoC) that provides Wi-Fi capable RF and Layer 2 processing. It provides clock speed up to 240MHz, built-in Wi-Fi and Bluetooth, and a rich set of peripheral interfaces (UART, I2C, SPI). It is ultra-low power, perfect for battery powered applications. It's built-in with the OTA firmware and a strong community, ESP32 has established itself as one of the go-to boards for IoT projects whether you are a hobbyist or a professional, due to its versatility, reliability and real-time performance.

LDR SENSOR

LDR- Light Dependent resistor, resistance drop as light intensity increases. Widely used in senseing device, as photo-detector of illumination, etc., such as the street lamp monitoring is automatically opened or shut down applications. Hook up micro controller, it can used as a dimmer, and it can also be used for light control which is controlled by light. But because they are slow and respond to room light, they must be calibrated often and with precision.

CURRENT SENSOR

Some electrical installations may have a current sensor which senses current (electricity) in a non-contact fashion using magnetic or Hall effect. Followers: Specifications Features The device comes in Multi aperture Current Transformers and Hall effect based Current Sensors and is targeted for industrial applications Current measurement by Current Sensing (Global Current Transformer). Applications The device is ideally suited as a VCC Power Fail Monitor for power monitoring of 2.5 – 3.5V system, and motor control and power management systems. … The time resolution is very high, the response time relatively fast and the decoupling galvanic.

VOLTAGE SENSOR

An electronic voltage sensor is a voltage sensor it is an electrician that inputs a voltage of (0.1-300V or more) and output an analog voltage (0-5V) proportional to the input voltage. It offers a safe method of measuring AC or DC voltage in an installation, and is used in multiple systems, including batteries, regulators, and electrical circuits. Crucial features are accuracy, voltage range, response time and electrical insulation.

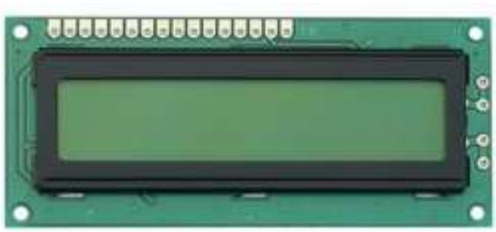
RELAY SWITCH

Relay is a switch operated 1 mA (0.001A) with a relatively small voltage, for example, 90V. When ordered, can be heard until with NO (normally open) contacts or NC (Normally Closed), if used in automation, home control and punk system. Relays provide galvanic separation and come in different forms, including electromechanical, solid-state, and reed relays for multiple applications.

DS18B20 SENSOR

The DS18B20 is a digital temperature sensor [10] that communicates over the 1-Wire protocol and allows multiple sensors on a single line. It provides high accuracy and 12-bit resolution over a temperature range of -55°C to 125°C and is specified for 2.7V to 5.5V sources and I2C communication. Ideal for home automation and mobile measurements, it supports parasitic power, a ±0.5°C maximum accuracy for 0°C to 65°C, and ±2°C accuracy from -10°C to +85°C.

LCD DISPLAY



LCD Official Feedback in Real-time LCDs in IoT systems present status information of sensors and devices, as long as system information. Displaying: They act as a natural user interface for the visualization and control of smart homes and industries. LCDs improve usablity and help save power by informing users nonsupervised interaction.

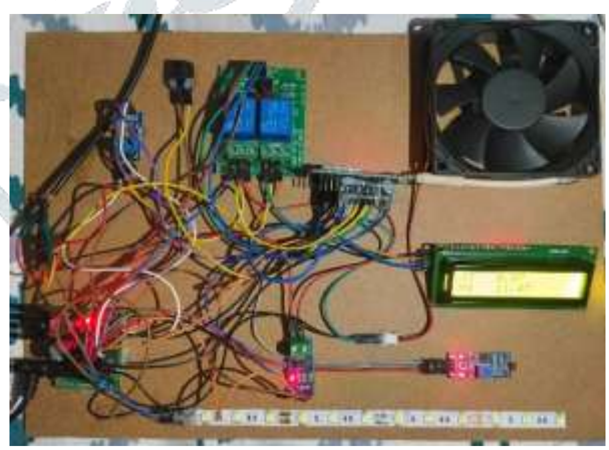
POWER SUPPLY

A/SO 6 Power Supply Board -Power transformer: 1,000 volts DC current, and high frequency conversion transformer: Power converter, virtual regeneration rectification, and pressure circuit A 12V power supply board consists of transformers, rectifiers and capacitor filters. It is perfect for electronics projects, automotive applications, LED lighting and anywhere you need to source a reliable 12V supply.

6 RESULTS

6.1 Model Performance

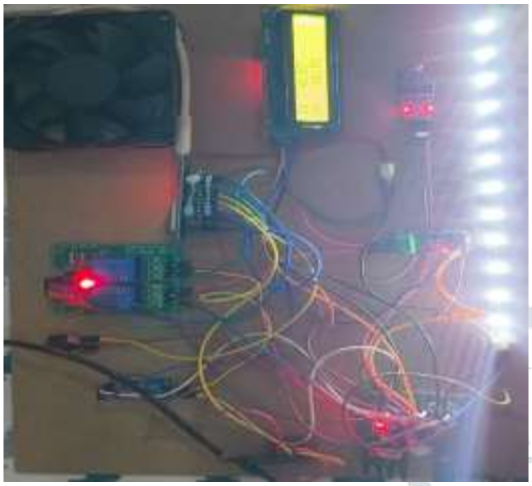
Figure 1: Setup Of Smart Home Energy Management System



The setup includes ESP32 microcontroller, relays, sensors (current, voltage, temperature, LDR), LCD display, and connected fan and LED strip for real-time monitoring and control. Here's a suitable heading for the new image you shared:

The system demonstrates automated control with fan and LED lights turned on, real-time energy readings displayed on the LCD, and sensors actively monitoring temperature, current, and voltage.

Figure 2: Light Automation In Action Using LDR Sensor

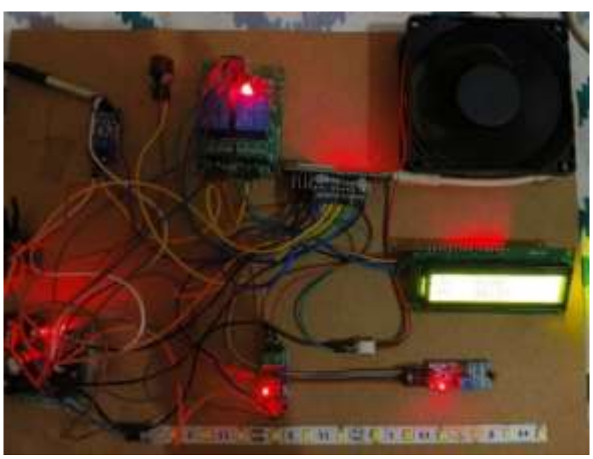


The system activates the LED strip automatically when ambient light levels fall below a threshold, as detected by the LDR sensor. Real-time current and voltage readings are displayed on the LCD screen, demonstrating the smart lighting control feature of the SHEMS.

Figure 3: Real-Time Temperature Display On LCD

The system displays real-time temperature (24.19°C) on the LCD screen using the DS18B20 digital temperature sensor. This reading is used to automate the fan control—turning it off when temperature falls below 30°C.

Figure 4: Fan Activation Based On Temperature Threshold



The system automatically turns on the fan when the ambient temperature exceeds 30°C, as detected by the DS18B20 sensor. The LCD displays real-time temperature and energy data, confirming active control through the relay module.

7 CONCLUSION

The proposed SHEMS offers an efficient way to reduce energy wastage of residential buildings using the Internet of Things (IoT) technologies. Utilizing an ESP32 based microcontroller and several sensors (LDR, LM35, DS18B20, and ACS712) the system continuously monitoring, light intensity, temperature and power consumption to actuate the on/off control to devices. This automation guarantees that appliances such as fans and lighting, only operate in the intervals they are needed, preventing unnecessary electricity use and providing peace of mind.

The integration with cloud services (e.g. Firebase, ThingSpeak) also complements the system providing remote access, real-time data visualization and historical analytics capabilities. Users can monitor energy usage trend and receive overuse alert in real time and make timely changes. Its LCD interface and mobile app support makes it so simple and hassle-free, that queries will make no less intimidating for users to start with.

While helping to save at the household level, the project contributes to overall environmental benefits by reducing carbon footprints. In addition, it is modular, so it can accommodate more components such as renewables integration and AIbased prediction algorithms to ensure the future system security.

It shows that the introduction of intelligent systems can cause a large revolution of patterns of energy consumption and power management in smart homes. Content With evolution in new technologies and consumer desires towards being eco-friendly, SHEMS can revolutionise the way people consume energy within a home.

Conclusion The proposed system that is introduced in this paper represents a step of smarter cities created by empowered households for energy efficient, convenient, and green life in an integrated way.

FUTURE ENHANCEMENT

There are some fields for improving the smart home energy management system in the future:

Integration into Smart Grid: Be sure to" smart-enable" the system for expanded functionality through integration into the smart grid's infrastructure. This would provide a two-way communication between the home and the utility company for demand response programs, optimization of energy tariffs, and grid stability.

Artificial Intelligence (AI) & Predictive Analytics: Utilizing deep learning AI algorithms and predictive analytics to predict energy consumption trends, find ways to save energy, and automate energy optimization through users" preferences and habit analysis.

Integration of Energy Storage: Integrating battery or other energy storage systems to collect surplus generated renewable energy and to minimize the waste of energy as much as possible by the demand side and grid status.

Behaviour recommendation: creating individualised behaviour recommendation on top of user's behaviour, demand and supply of energy and external influences, allowing actionable insights to save even more energy.

Better UI and Mobile Apps: Make the UI design better and have the mobile apps built in, so people can monitor and control their homes away from home without needing a computer.

Voice Assistant Supported: Use with Alexa or Google Assistant for voice control automation.

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