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IoT-Based Smart Energy Budget Monitoring and Predictive Cost Control System

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Abstract: *The demand for electricity is going up. Energy costs are rising. This means we need systems that can help us monitor and control how power we use. This paper is about an energy meter that works with a system to monitor and control energy costs. The system is for homes and laboratories. It uses a module to measure how much electricity is being used. This module is connected to a computer called an ESP32 microcontroller. The system measures things like how much voltage are being used. It also measures how much power is being consumed. All this information is sent to a platform. The platform shows us the information in a way that's easy to understand through a website. The system does more than just show us how energy we are using right now. It also tries to predict how energy we will use in the future. It does this by looking at how energy we used in the past. This helps people set budgets for their energy use. They get alerts when they are using much energy. This helps them make choices about how to use less energy. The system is designed to work with the systems we already have. This makes it easy to install and use. This system helps people understand how energy they are using. It helps them use energy in a way that costs less. It also helps us manage energy in a way that's good for the environment. The system is not too expensive. It can be used in many different places. This makes it a good choice, for homes and institutions that want to use energy in a way.*

Keywords: IIOT, Building automation, Smart energy meter, ESP 32 Microcontroller

I. INTRODUCTION

Electricity use in homes and small businesses has gone up a lot in the few years. This is because we have electrical infrastructure and we are using more modern appliances. Things like air conditioners, refrigerators and lighting take up a part of the energy we use. We need to make sure we are using energy efficiently and not wasting it because homes use a lot of energy overall. Usually we get our electricity bills after we have already used the energy. We get a report of how much energy we used but only after the month is over. This means we cannot see how energy we are using right now or make changes to use less energy. Sometimes we do not even realize we are using much energy until we get our bill and it can be really high.

There are tools that can track our energy use in real time and they show us the data in a way that is easy to understand. However these tools only show us how energy we are using they do not help us plan our budget. For example, they do not let us set a budget for the month or warn us if we are going to spend much money. Also, a lot of devices like plugs do not tell us how much each appliance is costing us or if we are going over our budget. The Internet of Things or IoT has made energy management better by letting us sense and control our energy use remotely. IoT devices can send data to the cloud, where it can be stored and analysed. For example, some microcontrollers have Wi-Fi, which lets them send data to the cloud all the time. Because of the problems with the way we do things now we are proposing a system that tracks our energy use and predicts how much it will cost.

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This system lets us set a budget for our electricity and it tracks how energy each appliance is using. It sends the data to the cloud, where it is processed to figure out how energy we are using each day and how much it will cost. One of the things about this system is that it can predict our electricity bill. It looks at how energy we are using each day and it estimates how much our bill will be for the month. It then compares this to our budget. If we are getting close to going over it sends us a warning. This helps us to use energy and it makes us more aware of how much energy we are using. The system is really helpful because it tells us when we are using much energy so we can do something about it. This way we can use energy efficiently and we can save money on our electricity bills. We think this system is an idea because it helps us to control our energy use and it makes sure we do not spend too much money. We believe that our Smart Energy Budget Monitoring and Predictive Cost Control System is a solution to the problems we have with energy use now. It helps us to use energy efficiently and it saves us money. We think it is an idea and we hope it will help people to use energy in a better way.

The goal of this system is to help people use energy efficiently and to save money on their electricity bills. We think it is a way to do this because it gives us the information we need to make good choices about our energy use. We hope that our system will be helpful to people and that it will make a difference in the way we use energy. In the end our system is designed to help people use energy in a way. It tracks our energy use. It predicts how much it will cost. It helps us to stay within our budget. It makes us more aware of how much energy we are using. We think it is an idea and we hope it will be helpful, to people. The major contributions of this work are summarized as follows:

• The application of IoT technology enables intelligent sensing, real-time data collection, and remote monitoring for effective energy management.

• The proposed framework integrates sensors, microcontrollers, wireless communication, and cloud computing to develop a scalable and interactive monitoring system.

• The use of modern microcontrollers such as ESP32 allows seamless Wi-Fi connectivity, enabling continuous data transmission and real-time visualization through cloud platforms.

This study introduces an energy monitoring approach tailored for smart home settings, focusing on budget considerations to connect traditional energy tracking with financial oversight. The system aims to be cost-effective, adaptable and compatible with current smart energy frameworks.

II. RELATED WORK

In years smart grid technologies and IoT-based monitoring systems have grown a lot. This has led to a lot of research into tracking energy in time and managing home energy smartly. Many methods have been tried to improve the understanding and use of energy data collected. This section looks at some works in this area and points out a specific gap that the proposed system wants to fill. Early energy monitoring solutions used microcontrollers like Arduino and Raspberry Pi. These setups used voltage and current sensors to capture data and sent it to local servers for display and analysis. They were okay for monitoring but had limited functionality. They did not offer features like predictive analytics, remote access or tools to manage energy costs effectively.

The growth of technology led to cloud-connected platforms. These platforms used communication protocols like Wi-Fi and MQTT to enable real-time data flow. Energy consumption information stored in the cloud could be accessed through web interfaces or mobile apps. This made it more convenient for users and improved data visualization. However, these enhancements mainly focused on tracking con Sumption not managing costs comprehensively. Key features like cost forecasting or budget-oriented monitoring were often missing. The development of smart plugs and home automation systems allowed for more detailed monitoring at the appliance level. Users could identify high-energy devices. Understand usage patterns better. However, these platforms usually did not support setting budgets or generating predictive alerts tied to electricity spending.

As a result, they were not very effective in helping users con troll expenses. Some studies used machine learning to forecast trends in energy consumption. This could improve prediction accuracy. Provide deeper insights into user behaviour. These methods often required significant computational resources and increased system complexity. Many

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of these models did not integrate user-defined constraints, which is important for practical energy management solutions.

In general, existing approaches usually treat energy consumption monitoring and cost management as processes. There is a need for a system that combines real-time monitoring with budgeting and predictive alert features. The proposed framework addresses this gap by adding a dimension to energy monitoring.

By combining energy tracking with cost prediction and budget awareness the system aims to give users actionable insights aligned with their spending limits. It wants to equip users not with consumption data but with the tools to manage their energy costs effectively. The system focuses on energy consumption and energy costs. It tries to fill the gap, in existing energy management solutions.

III. COMPARATIVE ANALYSIS

TABLE I

FEATURE	COMPARISION BETWEEN EXISTING SYSTEMS AND PROPOSED SYSTEM		
	TRADITIONAL	IoT	PROPOSED
Real-Time Monitoring	No	Yes	Yes
Appliance-Level Analysis	No	Limited	Yes
Cloud Data Storage	No	Yes	Yes
Monthly Budget Setting	No	No	Yes
Predictive Bill Estimation	No	Limited	Yes
Automated Alerts Budget	No	No	Yes
Cost Optimization Suggestion	No	Limited	Yes
Scalability	No	Moderate	High

IV. PROPOSED SYSTEM ARCHITECTURE

The Smart Energy Budget Monitoring and Predictive Cost Control System uses a kind of system with many layers. This system has parts that sense things communicate with each other process information in the cloud and show information to the user. This design helps people track how energy they use all the time guess how much it will cost based on a budget they set and sends them warnings when they are using too much energy.

A. Overall Architecture

The architecture consists of four primary layers:

1) Data Acquisition Layer
2) Communication Layer
3) Cloud Processing Layer
4) Application Layer

Each layer performs a specific role, helping achieve accurate energy monitoring and reliable cost analysis.

B. Data Acquisition Layer

The part that collects data is called the Data Acquisition Layer. It gets information about how much electricity things using right now. It does this with parts that can sense the current in devices that are being monitored. For example, the ACS712 current sensor or something similar measures how current each device is using. This sensor sends a signal that's like a message and this message is related to how much current is being used. The ESP32 microcontroller changes this message into information that the system can understand. After that the ESP32 looks at this information to figure out how much power is being used at that moment.

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$$P = V \times I$$

where P represents power (W), V is voltage (V), and I is current (A).

C. Communication Layer

The Communication Layer is in charge of sending information from the devices to the cloud. The ESP32 uses its built-in Wi-Fi to send the information it has collected. It uses ways of sending information like HTTP or MQTT to make sure the information gets to the cloud safely. This means people can check how energy they are using from far away and they do not have to physically read the meters.

D. Cloud Processing Layer

The Cloud Processing Layer is where all the information is stored and looked at. The information that the ESP32 sends is. Stored in a special database in the cloud. This makes it easy to get to and use when it is needed. Then the system uses this information to do things, such as:

- Calculating daily energy consumption
- Summarizing total usage on a monthly basis
- Estimating the cost according to the applicable tariff rate
- Predicting future electricity bills based on usage patterns

The estimated monthly cost is calculated by dividing the total cost incurred so far by the number of days passed and then multiplying it by the total number of days in the month.

$$\text{Predicted Cost} = (\text{Total Cost So Far} / \text{Days Elapsed}) \times \text{Total Days in Month}$$

This prediction method helps users anticipate their electric ity bill in advance, allowing better planning before the billing period is completed.

IV. PROPOSED SYSTEM ARCHITECTURE

A. Web Dashboard Implementation

The Application Layer has a web-based interface that helps users see how energy they are using right now guess how much it will cost and manage their electricity budget better. On the dashboard users can see how energy each appliance is using look at how they used energy all month and get notifications if they go over the budget they set.

The dashboard shows things like how much it cost today how much the bill will be for the month how many devices are on and how much budget is left. There is a circle that shows how much of the budget is already used so users can see how they are doing.

The system also lets users look at each appliance. Has a control panel to manage devices that are connected. The electricity consumption calculator module allows users to estimate daily and monthly electricity costs based on appliance wattage and usage duration. This feature assists users in understanding the impact of individual appliances on overall electricity expenditure.

The electricity calculator helps users figure out how much they spend on electricity every day and every month. They just put in how many watts the appliance uses and how long it is on. This helps users see how each appliance affects their energy bills. The Monthly Cost Analysis part uses graphs to show how energy each appliance uses. This way users can easily see which devices use the energy and change how they use them. Users can also set a budget for energy in the settings. Change other preferences. When users get close to their budget the system sends them a notification.

The Application Layer puts together real-time monitoring to understand graphs and simple controls to help users understand their energy use and be more efficient with their energy consumption. The Application Layer does this by giving users the tools they need to manage their energy budget and see how energy they are using. The Application Layer is, like a helper for users to keep track of their energy use and stay within their budget.

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VI. EXPERIMENTAL RESULTS AND PERFORMANCE ANALYSIS

Testing of the proposed IoT-based smart energy budget monitoring system took place under actual household load conditions. The setup involved an ESP32 microcontroller interfaced with a current sensor module to capture real-time energy usage data.

A. Experimental Setup

The experimental setup consisted of:

- ESP32 microcontroller used for collecting data
- ACS712 current sensor for measuring current
- Wi-Fi connectivity for transmitting data to the cloud
- Cloud database for storing energy data
- Web-based dashboard for displaying and analysing information

Different household appliances, including an air conditioner, refrigerator, lighting system, and television, were tested under controlled operating time conditions

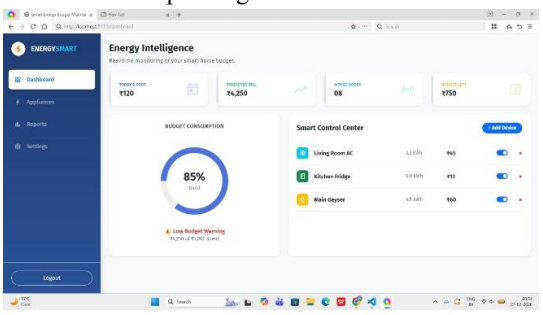

Fig. 1. Image of main dashboard

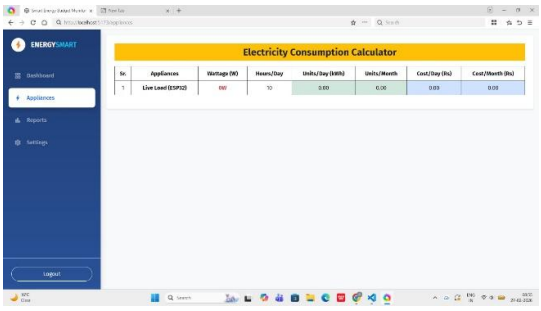

Fig. 2. Electricity Consumption Calculator

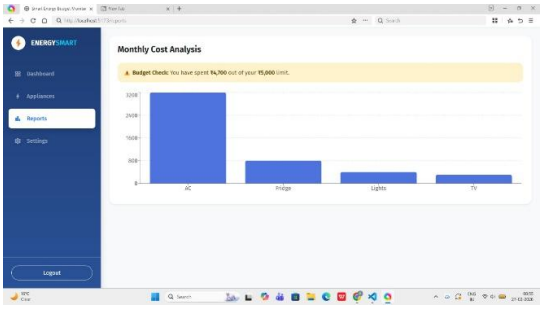

Fig. 3. Monthly Cost Analysis

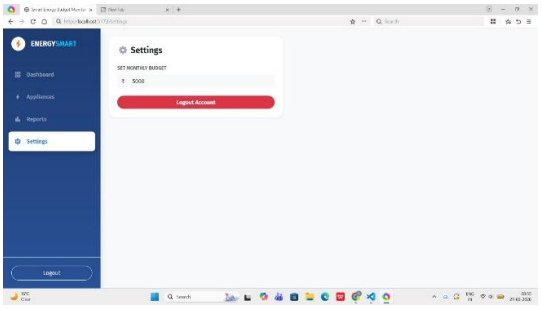

Fig. 4. Budget Configuration Interface Links

B. Energy Consumption Measurement

The instantaneous power usage is determined by multiplying the supply voltage with the current drawn by the appliance. The instantaneous power usage is determined by:

$$P = V \times I$$

where:

- V represents the supply voltage
- I represents the measured current

The total energy consumed over a period of time is calculated by multiplying power with the operating duration.

$$E = P \times t$$

where:

- E denotes energy (in kWh), • t denotes time in hour

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C. Energy Consumption Measurement

The system performance was assessed using several impor tant factors, including:

- Accuracy of real-time data measurement
- Delay in data communication
- Accuracy of budget prediction
- Ability of the system to scale with additional devices

D. Results

The experimental results revealed the following observations:

- Real-time energy data was refreshed with very low delay
- estimated monthly bill was closely aligned with expected values
- Budget alerts were generated accurately when the set limits were exceeded
- Appliance-level monitoring helped in better understanding energy usage patterns

The system maintained stable performance during continu ous operation and was able to handle multiple appliance nodes efficiently at the same time.

E. Discussion

The system they made combines Internet of Things sensing, cloud computing and predictive analytics to make energy management better. It is better than energy meters because it gives people a clearer picture of how much energy they are using sends them notifications on time and lets them have more control over how much they spend on electricity.
The system also helps people understand how they spend their money on energy by looking at what they might spend in the future. This helps people use energy in an efficient and responsible way

VII. CONCLUSION

This study is about a system that uses the Internet of Things to help people monitor their energy budget and predict how much it will cost. It is meant to help people be more aware of how they use energy and plan their money better at home. The system looks at how much energy's being used in real time and uses cloud computing to predict how much it will cost. This helps people manage their energy use and the money they spend on it. The system works by using a sensor to monitor how much energy is being used now.
This information is sent to a platform where it is looked at and processed. People can look at a website to see how energy they are using predict how much they will spend and get warnings if they are getting close to spending too much. The results of trying out the system show that it works well does not take long to send information and is good at predicting costs. The system is practical. Can be used in many places, like homes and small businesses because it combines energy tracking with financial limits.
Overall the system helps people make decisions and use energy in a way that is good for the environment by combining monitoring, prediction and control into one solution. The system is all about energy management. It really helps with energy management. The energy management system is very useful, for people who want to use energy management to save money and use energy.

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