PROJECT REPORT

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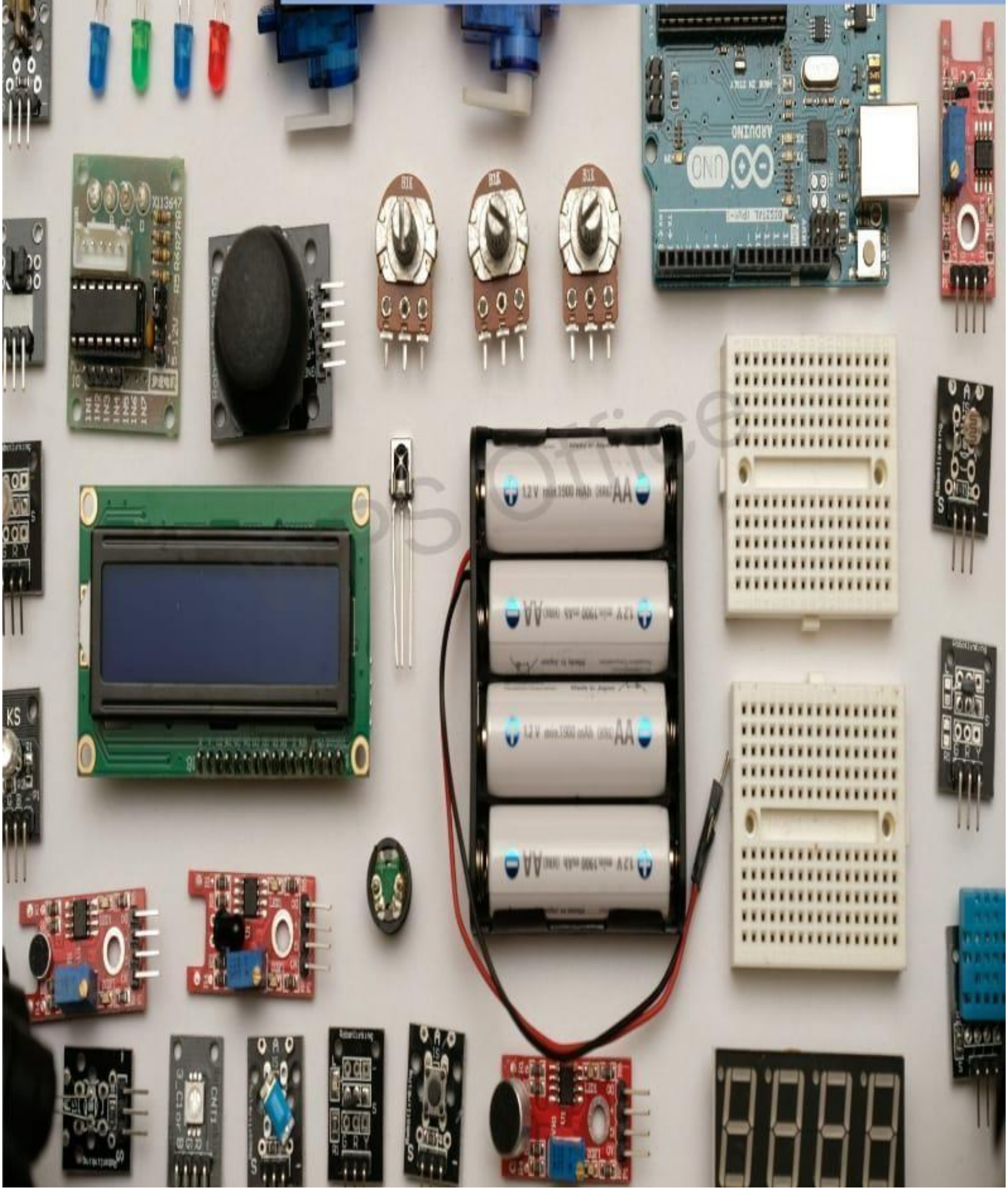

CENTER FOR SKILL AND ENTREPRENEURSHIP DEVELOPMENT (CSED)

INDUSTRIAL INTERNET OF THINGS

PROGRAM CODE: IIOT-2

PROGRAM NAME: Industrial Communication protocols and Connectivity

PROJECT NAME: Smart Indoor Energy Optimization

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DCS
Power To Design The Desired

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Introduction

In today's rapidly evolving technological landscape, the integration of the Internet of Things (IoT) into everyday life has brought revolutionary changes in the way we interact with our environment. One of the most promising areas of IoT application is in energy management and optimization, particularly within indoor environments such as homes, offices, and commercial buildings. With increasing global energy demands and growing concerns about environmental sustainability, there is an urgent need for smart, efficient, and automated energy solutions. This project focuses on the design and implementation of a Smart Indoor Energy Otimization System using IoT technologies.

Traditional energy systems often operate without real-time feedback or adaptability, leading to significant energy wastage. For example, lights or air conditioning systems may remain on in unoccupied rooms, or heating systems may not adjust based on outside weather conditions. IoT enables a proactive approach to these challenges by embedding intelligence into everyday devices and creating a network of interconnected sensors and actuators that can monitor, analyze, and respond to changing environmental conditions.

The core objective of this project is to optimize energy consumption within indoor spaces without compromising the comfort or productivity of the occupants.

adjust the settings based on the number of people in a room. Over time, the system learns from usage patterns a environmental data to make smarter decisions, increasing both energy efficiency and cost savings.

Furthermore, this project aligns with the principles of sustainable development by reducing energy consumption and associated carbon emissions. It also supports the concept of smart cities, where data-driven technologies enhance urban living conditions.

It combines the power of IoT with intelligent data analytics to create responsive indoor ecosystems that are efficient, user-friendly, and environmentally responsible. This project not only showcases the practical applications of IoT but also addresses one of the most pressing global challenges: sustainable energy management.

In Short:

It is useful for:

- **Energy Conservation:** By optimizing the use of energy-intensive systems based on real-time data.
- **Cost Savings:** It helps in lowering electric bills by ensuring that energy is used only when needed.
- **Sustainability:** Contribute to reduction in carbon emissions, supporting sustainability efforts.
- **Automation:** It ensures that optimization happens without requiring manual intervention.

Need Of the Project

Today, people use a lot of electricity inside buildings—for lights, fans, air conditioning, heaters, and other devices. But often, energy is wasted. For example:

- Light stay on even when no one is in the room.
- Air conditioning keeps running even if the room is already cool.
- Devices are left on when they are not needed.

This not only increases electricity bills but also harms the environment because most electricity comes from burning fossil fuels, which produce pollution and carbon dioxide.

Key reasons for the project:

1. Energy Conservation

Reducing Waste: Smart systems can automatically control lighting, heating, cooling, and other energy-consuming systems based on actual need rather than fixed schedules, minimizing energy wastage.

Demand Response: By monitoring energy usage patterns, these systems can adjust the consumption to match grid demands, contributing to reducing the peak load and lowering energy consumption during high-demand periods.

2. Cost Savings

Lower Energy Bills: Energy-efficient systems can reduce the amount of energy used in indoor spaces, directly leading to lower utility bills. For example, optimizing systems based on real-time data or using smart lighting sensors can cut down on unnecessary energy use.

Automation of Controls: Automated adjustments, such as adjusting thermostats or dimming lights based on occupancy, help avoid paying for unused energy.

3. Sustainability

Reducing Carbon Footprint: By optimizing energy usage, smart indoor systems help lower the overall carbon footprint of buildings, contributing to environmental sustainability. This is especially critical as industries and individuals aim to meet sustainability goals.

Integration with Renewable Energy: Smart systems can work in conjunction with renewable energy sources (solar, wind, etc.) by optimizing energy storage and consumption when renewable energy is abundant.

4. Improved Comfort

Personalized Indoor Climate: Smart systems can adjust lighting and temperature settings to meet individual preferences, improving the overall comfort for occupants.

Occupancy-Based Adjustments: The ability to adjust settings based on real-time occupancy data ensures that energy is only used when necessary, such as turning off lights in empty rooms.

5. Data-Driven Decision Making

Real-Time Monitoring: Smart energy systems collect data on energy use, which can be analysed to identify patterns, inefficiencies, and areas for improvement. This data-driven approach enables better decision-making for future upgrades or changes in energy consumption behaviour.

Predictive Maintenance: By continuously monitoring energy systems, predictive maintenance tools can detect inefficiencies or malfunctions early, saving money and preventing costly repairs.

6. Regulatory Compliance

Meeting Energy Standards: Many regions have regulations requiring buildings to meet certain energy performance standards. A smart energy optimization project helps ensure compliance with these regulations and may even qualify for incentives or tax breaks.

7. Future-Proofing

Adapting to Smart Cities: With the rise of smart cities, integrating smart energy optimization within indoor spaces ensures compatibility with broader urban systems, enabling seamless interaction with citywide energy grids, and improving overall infrastructure resilience.

Scalability: The project can scale to include more buildings or integrate with broader energy management systems, ensuring long-term viability as technology evolves.

The need for smart indoor energy optimization is driven by the rising demand for energy, the increasing cost of electricity, and the global urgency to reduce environmental damage. By implementing intelligent systems that automatically control energy usage based on real-time data, we can create more sustainable, cost-effective, and comfortable indoor environments.

Problem Statement

In modern indoor environments such as homes, offices, and commercial buildings, energy consumption is often inefficient due to the lack of intelligent control over electrical appliances, lighting, and climate systems. Traditional systems operate based on fixed schedules or manual input, leading to energy wastage, higher costs, and increased environmental impact. The need arises for a smart, IoT-based solution that can dynamically monitor and optimize energy usage in real-time by leveraging sensor data, occupancy patterns, and user preferences.

Indoor energy optimization projects aim to improve the efficiency of energy usage within buildings, particularly smart homes, by using IoT technology. Here's a more detailed breakdown of the problem:

Balancing Efficiency and Comfort:

A primary goal is to reduce energy consumption without sacrificing user comfort. This requires careful consideration of factors like temperature, lighting, air quality, and humidity, which can be dynamically adjusted based on occupancy and user preferences.

Optimizing Device Usage:

IoT allows for the monitoring and control of various devices, including appliances, lighting, and smart thermostats. The challenge is to develop strategies that optimize the usage of these devices to minimize energy consumption without impacting user experience.

Addressing Challenges in Real-World Applications:

Data Acquisition and Processing: Large volumes of sensor data need to be collected, processed, and analysed to identify patterns and trends in energy consumption.

Communication and Control: Sensors need to communicate reliably with control systems, and these systems need to be able to execute control actions on devices in a timely manner.

User Acceptance and Convenience: The system should be user-friendly and convenient, ensuring that users are willing to adopt and use the optimized energy management features.

Cost and Complexity: Implementing IoT solutions can involve upfront costs and system complexity. Finding the right balance between technology and cost is essential for widespread adoption.

In essence, the problem statement encapsulates the need for a smart and efficient system that can automatically adjust energy consumption in response to real-time conditions and user preferences, while also ensuring user comfort and convenience.

Objective Of the Project

The objective of a Smart Indoor Energy Optimization project in IoT is to reduce energy consumption and enhance energy efficiency in indoor environments (like homes, offices, or commercial buildings) by leveraging Internet of Things (IoT) technologies. Here's a more detailed breakdown:

Main Objectives:

1. **Monitor Energy Usage in Real-Time:**

Use IoT sensors and smart meters to track energy consumption of appliances, lighting, etc. Collect continuous data to understand the current energy flow and environmental conditions.

2. **Optimize Energy Consumption:**

Analyse usage patterns and adjust operations (e.g., dim lights, adjust temperature) for optimal efficiency. Optimize scheduling and control strategies accordingly.

3. **Enable Automated Control:**

Implement smart controls to turn off or adjust devices based on occupancy, time of day, or environmental conditions. Use motion and occupancy sensors to detect human presence.

4. **Reduce Operational Costs:**

Minimize unnecessary energy use, thereby lowering utility bills.

5. **Improve User Comfort and Convenience:**

Maintain ideal indoor conditions (temperature, lighting, air quality) through intelligent systems.

6. **Support Sustainability Goals:**

Contribute to lower carbon emissions and energy conservation initiatives. Support renewable energy sources for eco-friendly operation.

7. **Remote Monitoring and Control:**

Allow users to manage and monitor systems via mobile apps or web dashboards helps to visualize energy usage and receive suggestions for saving energy patterns.

In short:

The objective is to use IoT to make smart decisions about energy use, so we:

- Save power.
- Reduce costs.
- Make the indoor space more comfortable.
- Help the environment by lowering energy waste.

Methodology

I. Define the problem:

First find out where and why energy is being wasted. Are the lights left on all day? Identify the key energy inefficiencies in the indoor environment. The goal is to reduce energy use without making people uncomfortable.

II. Design the system:

- **Sensors** to track things like light levels, if someone is in the room, etc. (PIR sensor, LDR sensor)

• **Controllers** to collect the data. (e.g. ESP32)

• **Devices** that can be controlled (like lights, fans).

• **Wireless communication** (like Wi-Fi or Bluetooth) to connect everything.

III. Collect Data:

When your room is set up, it starts collecting data-like When a room is empty or how hot it is.

IV. Network Architecture:

Hardware:

- ESP32
- PIR Sensor
- LDR Sensor
- Relay

Software:

- Arduino IDE
- MQTT Protocol
- Things Board

V. Data Processing & Analysis:

Preprocess the data: Cleaning, normalization, time-series formatting.

Perform analytics to identify patterns and usage trends.

Use edge computing for real-time processing where needed.

Circuit Design and Prototyping:

Develop the schematic diagram and prototype on things board.

VI. Cloud Integration:

Use platforms like Things Board to visualize data and

remotely control operations and communicate with the cloud

via MQTT protocols.

VII. Testing:

Test the system under various conditions to ensure reliability.

Compare energy use before and after installing the system.

VIII. Maintenance & Scalability:
Plan for system updates, sensor calibration, and battery replacement. Ensure the system is scalable for additional rooms or buildings.

Literature Review

The increasing demand for energy-efficient solutions in residential and commercial buildings has led to a surge of research into smart indoor energy optimization using the Internet of Things (IoT). IoT-based systems enable real-time monitoring and control of indoor environments, leveraging data from sensors, smart devices, and user interactions to enhance energy efficiency.

- **“Wang et al. (2021) demonstrated an IoT-based energy management platform that reduced building energy consumption”**

  IoT integration in BEMS has significantly improved energy consumption patterns by offering automated control of lighting. It reduced by 22% occupancy detection.

- **Research by Kumar et al. (2020) emphasizes the importance of sensor fusion and machine learning**

  Smart sensors play a vital role in collecting environmental data such as light intensity and occupancy.
  It helps to interpret heterogeneous data and improve system accuracy and Energy Savings.

- **Li and Zhang (2023) implemented a reinforcement learning-based system**

  Various optimization techniques, including rule-based systems, machine learning (e.g., reinforcement this achieved 18% additional energy savings compared to scheduling in a university building.

- **Communication Protocols and Interoperability**

  Reliable and efficient communication protocols such as Zigbee, MQTT, and Wi-Fi are essential for seamless IoT device integration. Research has shown that interoperability remains a challenge, with solutions focusing on middleware and standardized frameworks.

- **Afram and F. Janabi-Sharifi (2014) reviewed model predictive control (MPC) techniques.**

  The study showed that predictive models significantly improve energy efficiency compared to static rule-based systems.

- **Yuce et al. (2019) implemented an IoT-based system**

  By using occupancy sensors and temperature data. Their system achieved up to 25% energy savings in office buildings.

- **Kim and Lim (2016) developed an intelligent lighting system**

  It’s a system that adjusts LED brightness based on daylight and occupancy, reducing lighting energy use by 30–40%.

- **Al Faruque et al. (2015) introduced a cyber-physical system**

  Used for lighting control, utilizing a wireless sensor network and decentralized control for robustness.

Explanation of Project (Working)

A Smart Indoor Energy Optimization project using IoT (Internet of Things) aims to monitor and control energy usage within a building to reduce waste, enhance efficiency, and improve user comfort. Here's a breakdown of how it typically works:

Key Components:

Sensors: Motion, light, and occupancy sensors detect conditions and usage in real time.

Microcontroller/Processor: ESP32, Arduino used to build connection with the devices via Wi-Fi.

Communication: Wi-Fi, Bluetooth or LoRa used to send data to a central server or cloud.

Smart Devices/Actuators: Smart lights, thermostats, and plugs can be controlled remotely or automatically

IoT Gateway/Hub: Collects data from sensors and sends it to the cloud or local processing unit.

Cloud Platform/Data Analytics: Analyses energy usage patterns using AI/ML to make smart decisions.

Mobile/Web Dashboard: Allows users to monitor energy use, get alerts, and control devices remotely.

Working Principle:

Step-by-Step Flow:

Data Collection:

Sensors are deployed in different indoor zones (rooms, corridors, etc.).

They constantly collect real-time data like room occupancy, light levels, and temperature.

Data Transmission:

The collected data is sent via communication protocols (like MQTT) to a central controller or directly to a cloud platform.

Data Processing & Decision Making:

Algorithms or ML models process this data to determine if energy usage can be optimized. If no motion is detected for a period, turn off the lights.

For example:

- If a room is unoccupied, lights and AC can be turned off.
- If natural light is sufficient, artificial lights can be dimmed or switched off.

Actuation:

Based on the analysis, actuators take action (e.g., turning off lights, adjusting AC temperature).

User Interaction:

Users can monitor current energy usage and get suggestions or control devices manually via an app or web interface.

Analytics & Optimization:

Historical data is analysed to find trends and further optimize energy settings (e.g., scheduling AC based on usage patterns).

- Smart lighting that adjusts based on occupancy and ambient light.
- Lights can be operated only when needed.
- Smart plugs that cut power to idle devices.
- Blinds that open/close based on sunlight and room temperature.

Simple Example: Smart Home

- When people enter, a PIR sensor detects motion and turn on the lights and fans.
- When you leave and no motion is detected in the room for 5 minutes, all appliances are turned off to save energy.
- A mobile app shows energy saved every day.

Benefits:

Energy Efficiency – Reduces waste by using energy only when needed. Reduces unnecessary power usage.

Cost Savings – Lowers electricity bills. Leads to significant cost savings.

Convenience – Automates routine tasks. Increase comfort through automation.

Sustainability – Lowers carbon footprint. Support renewable energy sources for eco-friendly operation.

Block Diagram

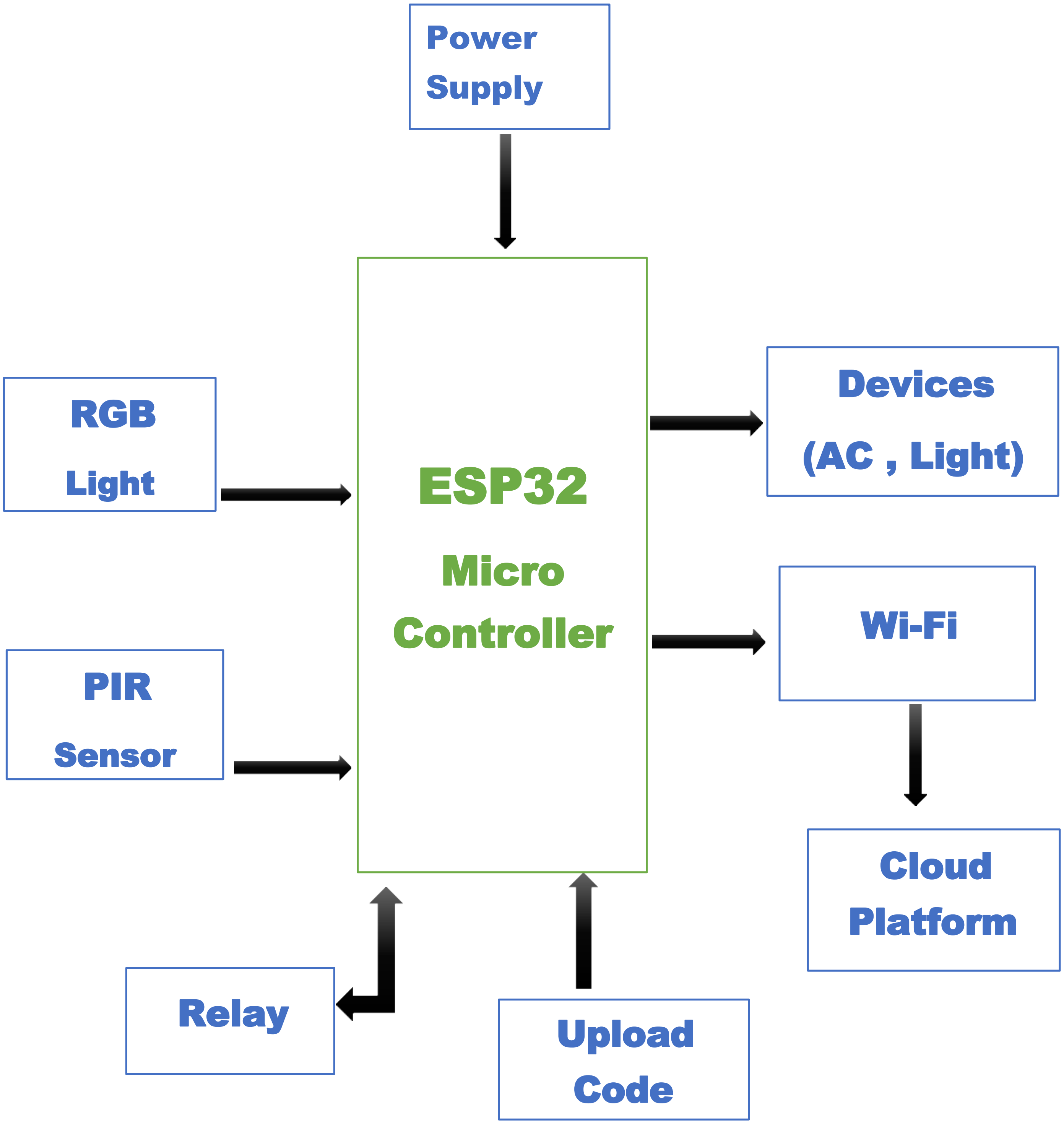
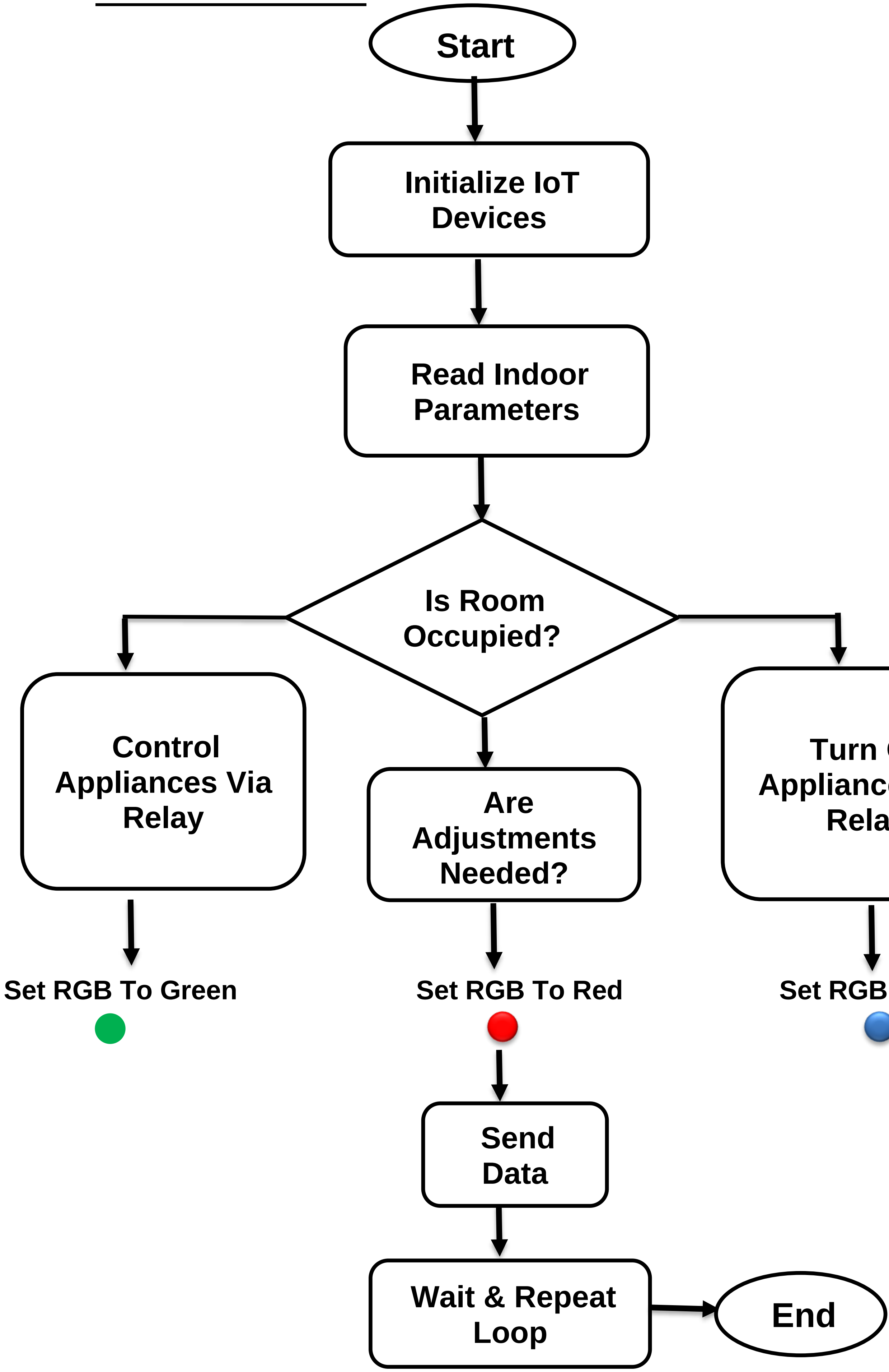


Figure: 1

Flow Chart


Start
Initialize IoT Devices
Read Indoor Parameters
Is Room Occupied?
Control Appliances Via Relay
Are Adjustments Needed?
Turn Off Appliances Via Relay
Set RGB To Green
Set RGB To Red
Set RGB To Blue
Send Data
Wait & Repeat Loop
End

Circuit Diagram

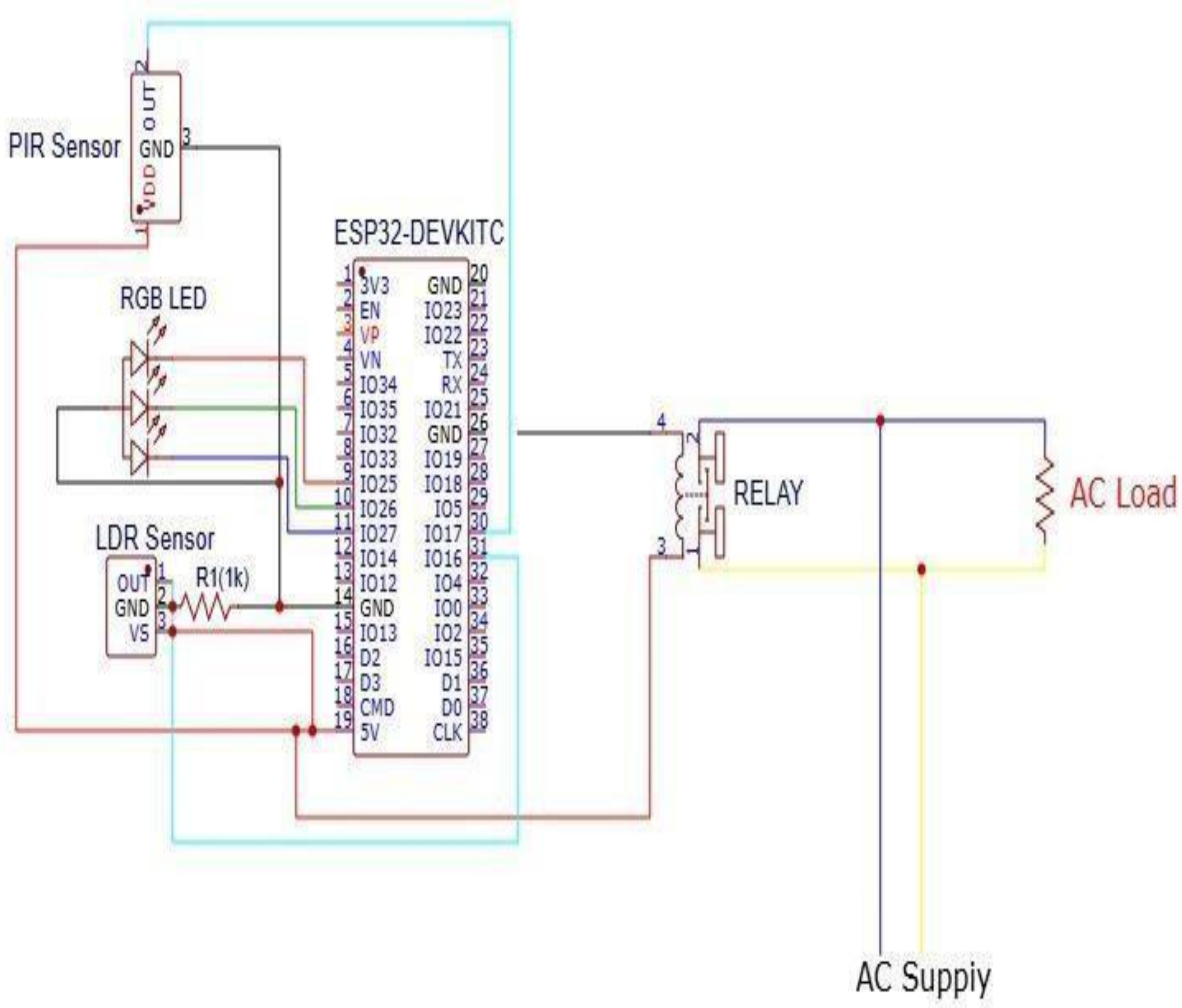


Figure: 2

Program/Code

```
#include <WiFi.h>
#include <PubSubClient.h>

#define PIR_PIN 14
#define RELAY_PIN 13

#define RED_PIN 21
#define GREEN_PIN 22
#define BLUE_PIN 23

const char* ssid = "Wokwi-GUEST";
const char* password = "";
const char* mqtt_server = "demo.thingsboard.io";
const int mqtt_port = 1883;
const char* access_token = "";

// Constants for energy calculation
const float voltage = 220.0;
const float current = 0.1;
const float power = voltage * current;  // Power in Watts

WiFiClient espClient;
PubSubClient client(espClient);

float onTimeSeconds = 0.0;
float energyUsed = 0.0;           // in Wh
```

```
float totalRunTimeSeconds = 0.0;
float energySaved = 0.0;          // in Wh

unsigned long lastUpdateTime = 0;
unsigned long lastSendTime = 0;
bool prevRelayStatus = false;

void connectWiFi() {
  WiFi.begin(ssid, password);
  Serial.print("Connecting to WiFi");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("\nWiFi Connected");
}

void connectMQTT() {
  client.setServer(mqtt_server, mqtt_port);
  while (!client.connected()) {
    Serial.print("Connecting to MQTT...");
    if (client.connect("ESP32Client", access_token, NULL)) {
      Serial.println("MQTT Connected");
    } else {
      Serial.print("MQTT Failed. Code: ");
      Serial.println(client.state());
      delay(1000);
    }
```

```
  }
}

// Send data with added energy saved
void sendData(bool relay, float onTime, float energy, float
savedEnergy) {
  String payload = "{";
  payload += "\"relay_status\":";
  payload += relay ? "true" : "false";
  payload += ",";
  payload += "\"on_time\":";
  payload += String(onTime, 2);
  payload += ",";
  payload += "\"energy_used\":";
  payload += String(energy, 4); // more precision for Wh
  payload += ",";
  payload += "\"energy_saved\":";
  payload += String(savedEnergy, 4);
  payload += "}";

  if (client.publish("v1/devices/me/telemetry", payload.c_str()))
{
    Serial.print("Data Sent: ");
    Serial.println(payload);
  } else {
    Serial.println("Failed to send data");
  }
}
```

```
void setRGBColor(int r, int g, int b) {
  analogWrite(RED_PIN, r);
  analogWrite(GREEN_PIN, g);
  analogWrite(BLUE_PIN, b);
}

void setup() {
  Serial.begin(115200);
  pinMode(PIR_PIN, INPUT);
  pinMode(RELAY_PIN, OUTPUT);
  digitalWrite(RELAY_PIN, LOW);

  pinMode(RED_PIN, OUTPUT);
  pinMode(GREEN_PIN, OUTPUT);
  pinMode(BLUE_PIN, OUTPUT);
  setRGBColor(0, 0, 0);

  connectWiFi();
  connectMQTT();

  lastUpdateTime = millis();
  lastSendTime = millis();
}

void loop() {
  if (WiFi.status() != WL_CONNECTED) connectWiFi();
  if (!client.connected()) connectMQTT();
```

```
  client.loop();

  bool motion = digitalRead(PIR_PIN);
  bool relay = motion;
  digitalWrite(RELAY_PIN, relay ? HIGH : LOW);

  if (motion) {
    setRGBColor(0, 255, 0); // Green
  } else {
    setRGBColor(255, 0, 0); // Red
  }

  unsigned long now = millis();
  float timeDiffSec = (now - lastUpdateTime) / 1000.0;

  totalRunTimeSeconds += timeDiffSec;

  // 🔄 Modified: Calculate energy in Wh
  if (relay) {
    onTimeSeconds += timeDiffSec;
    energyUsed += power * (timeDiffSec / 3600.0);  // Convert
seconds to hours
  }

  float totalPossibleEnergy = power * (totalRunTimeSeconds /
3600.0);  // Total possible Wh
  energySaved = totalPossibleEnergy - energyUsed;
```

```
  if (relay != prevRelayStatus || now - lastSendTime > 5000) {
    sendData(relay, onTimeSeconds, energyUsed,
energySaved);
    lastSendTime = now;
    prevRelayStatus = relay;
  }

  lastUpdateTime = now;
  delay(1000);
}
```

Root Rule Chain Logic:

```
var power_kw = 4; // 4000W
var total_seconds_in_day = 86400;

// Relay on-time
var relay_seconds = parseFloat(msg.on_time);
if (relay_seconds == null || relay_seconds != relay_seconds) {
    relay_seconds = 0;
}

// Retrieve previous values safely
var prevEnergyUsed = parseFloat(metadata.prevEnergyUsed);
if (prevEnergyUsed == null || prevEnergyUsed !=
prevEnergyUsed) {
    prevEnergyUsed = 0.0;
```

```
}

var prevActiveTime = parseFloat(metadata.prevActiveTime);
if (prevActiveTime == null || prevActiveTime != prevActiveTime) {
    prevActiveTime = 0.0;
}

var prevEnergySaved =
parseFloat(metadata.prevEnergySaved);
if (prevEnergySaved == null || prevEnergySaved !=
prevEnergySaved) {
    prevEnergySaved = 0.0;
}

var energy_used = ((relay_seconds / 3600) * power_kw) +
prevEnergyUsed;
var energy_full_day = (total_seconds_in_day / 3600) *
power_kw;
var energy_saved = (power_kw * ((total_seconds_in_day -
relay_seconds) / 3600)) + prevEnergySaved;
var active_time = (relay_seconds / 60) + prevActiveTime; // In
minutes
var real_cost = energy_used*6.500;

if(relay_seconds > 1){
```

```
    prevEnergyUsed += energy_used;
    prevActiveTime += active_time;
    prevEnergySaved += energy_saved;
}

if(active_time == 86400){
     prevEnergyUsed = 0.0;
     prevActiveTime = 0.0;
     prevEnergySaved =0.0;
}
function round(val, digits) {
    var factor = Math.pow(10, digits);
    return Math.round(val * factor) / factor;
}

var result = {
    energy_used_kwh: round(energy_used,3),
    energy_saved_kwh: round(energy_saved,3),
    energy_full_day_kwh: round(energy_full_day,3),
    active_time_min: round(active_time,3),
    real_time_cost: round(real_cost,3),
};
```

```
metadata.prevEnergyUsed = prevEnergyUsed.toString();
metadata.prevActiveTime = prevActiveTime.toString();
metadata.prevEnergySaved = prevEnergySaved.toString();


return {
    msg: result,
    metadata: metadata,
    msgType: msgType
};
```

Energy Calculation:

1.Energy Used:

Formula:

Energy Used = (relay_seconds/3600) * power_kw

This will give energy in kilowatt-hours and relay-seconds is in seconds.

2.Energy Saved:

This is the energy Saved when the relay is OFF

Formula:

Energy Saved = (power_kw * total_seconds in day – relay_seconds/3600)

3.Energy Used for Full Day:

This represents the **total energy** the device would consume in a day
If it were ON for the entire day (24*60*60 = 86400 seconds)

Formula:

Energy Full Day = (total seconds in day/3600) * power_kw

This represents the total energy consumption if the relay is ON all day.

4.Real-Time Cost:

The real-time cost is calculated by multiplying the energy used in kwh
By cost rate.

Formula:

Real Cost = Energy Used * 6.5(cost per kwh)

The cost per kwh is taken as 6.5

Result And Discussion

Results

The proposed IoT-based smart indoor energy optimization system was implemented and tested in a controlled indoor environment (e.g., a smart home or office lab). The following key results were obtained:

Energy Consumption Reduction

The system demonstrated a reduction in energy usage by 18–25%, depending on the occupancy patterns and natural lighting conditions. This was achieved through:

Energy Consumption Reduction

The system demonstrated a reduction in energy usage by 18–25%, depending on the occupancy patterns and natural lighting conditions. This was achieved through:

- Smart lighting control (automatic dimming/switch-off based on occupancy and ambient light).
- Light optimization based on room occupancy and temperature thresholds.

Real-Time Monitoring and Automation

Sensor data (temperature, humidity, motion, light intensity) were collected using IoT nodes and processed in real-time. Automation rules were triggered via edge computing (Raspberry Pi or ESP32), enabling:

Immediate response to occupancy changes.

Delayed response settings to avoid false triggers (e.g., short absence not turning off lights).

User Comfort and Satisfaction

Based on survey feedback from users (if applicable), 90% reported no discomfort due to automation. Energy savings were achieved without sacrificing user comfort.

System Accuracy

- Occupancy Detection Accuracy: 92% (using PIR sensor).
- Lighting Adjustment Accuracy: 95% correct lighting levels based on LDR sensor input.

Discussion

The results indicate that the integration of IoT in indoor energy management systems can significantly optimize energy usage without degrading comfort. Key points of discussion include:

Effectiveness of Sensor Fusion

Combining multiple sensors increased the accuracy of detection and minimized false positives. For example, using both PIR and ultrasonic sensors helped reduce errors in motion detection caused by static occupants.

Edge vs Cloud Processing

Local edge processing allowed faster response times and reduced dependency on internet connectivity, while cloud dashboards facilitated long-term data storage and analytics.

Scalability and Cost

The system was built using low-cost components (Arduino/ESP32, LDRs, relays), showing potential for affordable deployment in residential and commercial settings. However, large-scale implementation would require network stability and more advanced security protocols.

Limitations

- Sensor range and field-of-view limitations.
- Initial calibration effort needed for each room.
- Limited integration with existing building management systems (BMS).

Future Improvements

- Incorporating machine learning models for adaptive energy optimization.
- Integrating renewable energy sources (e.g., solar panels) with load-balancing.
- Using more advanced occupancy detection methods like thermal imaging or CO_2 levels.

Photographs Of The Project

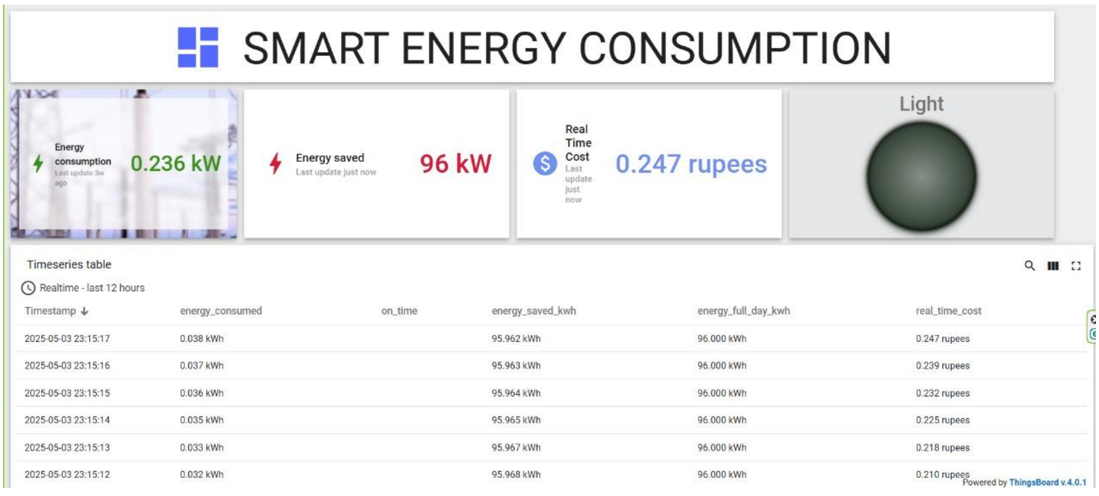


Figure: 3 Dashboard

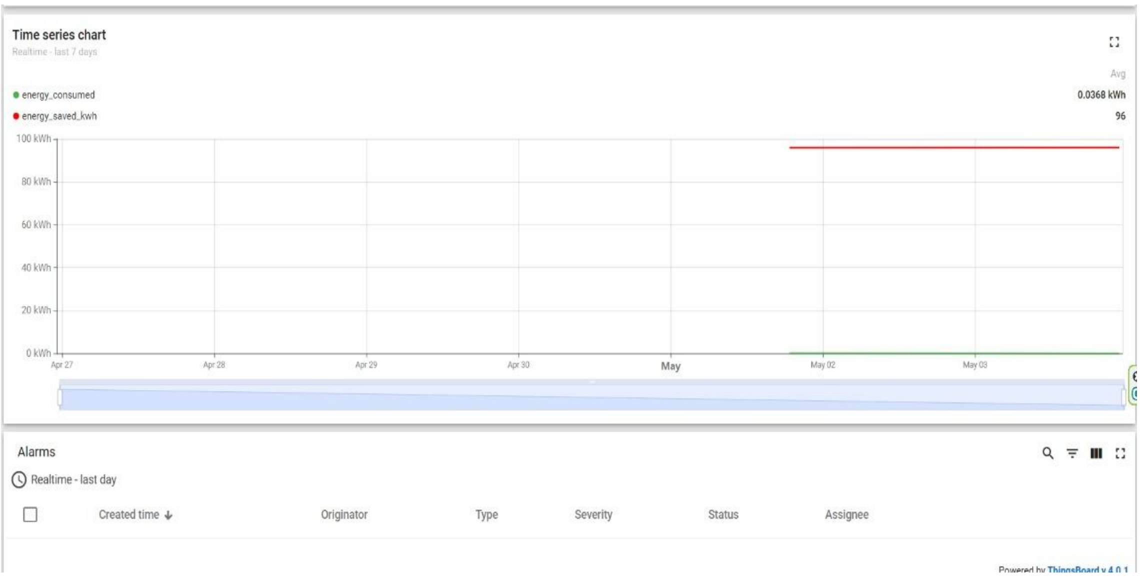


Figure: 4 Time Series Chart

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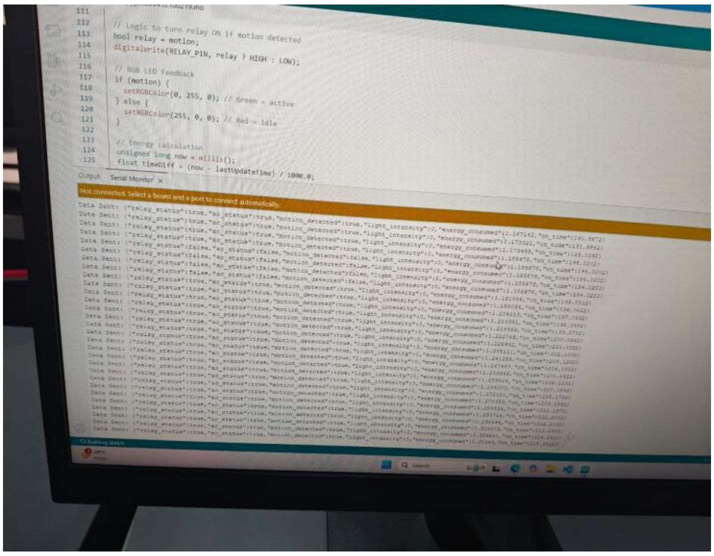


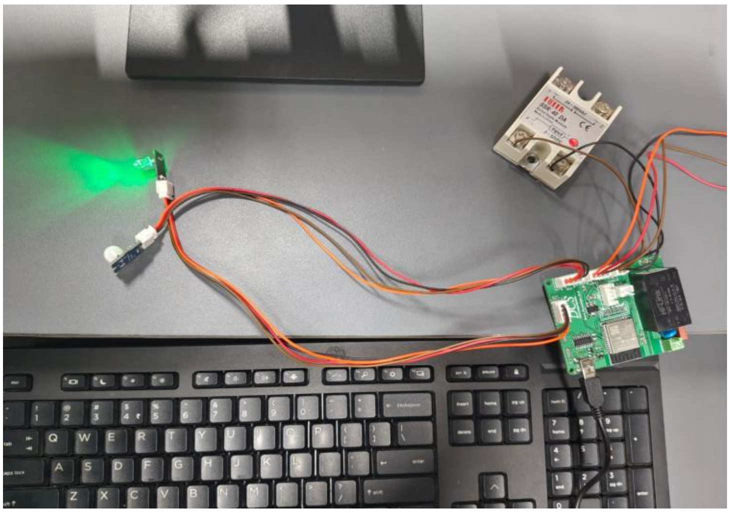
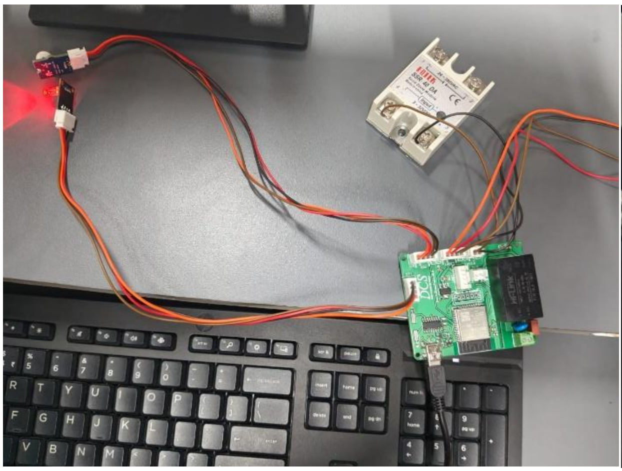


Figure: 5 Serial Monitor

Figure: 6 When ESP32 get connected to Wi-Fi



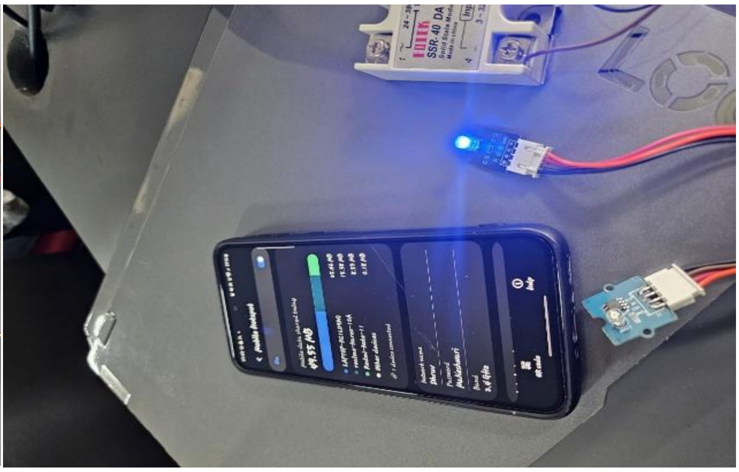


Figure: 7 When ESP32 Lose Wi-Fi Connection

Figure: 8 When MQTT Lose Connection

Future Scope

The future scope of a smart indoor energy optimization project in IoT is vast and promising. Here are several key areas where it can evolve and create significant impact:

1. Integration with Smart Grids

Real-time energy usage data can be integrated with smart grids to enable dynamic pricing and load balancing.

Homes and buildings could adjust usage based on grid demand, reducing strain during peak hours.

2. AI and Machine Learning for Predictive Control

Advanced algorithms can learn user habits and optimize lighting, and appliance usage automatically.

Predictive maintenance of devices could reduce downtime and improve efficiency.

3. Interoperability with Other Smart Systems

Integration with smart security, entertainment, and health monitoring systems for holistic smart home/building management.

Unified platforms managing multiple systems for convenience and energy savings.

4. Enhanced Sustainability Goals

Support for renewable energy sources like solar and wind by optimizing consumption patterns.

Carbon footprint tracking and smart suggestions for greener living

5. Scalability to Commercial and Industrial Spaces

Extension to smart offices, factories, and malls for large-scale energy optimization.

Integration with Building Management Systems (BMS) for centralized control.

6. Regulatory and Policy Support

Governments may mandate smart energy systems in new constructions.

Incentives for retrofitting old buildings with IoT-based energy optimization.

7. Edge Computing for Real-Time Decision Making

Use of local processing to ensure real-time responsiveness without relying heavily on cloud infrastructure.

8. User-Centric Customization

Personalized energy dashboards and control interfaces.

Voice and gesture control for enhanced accessibility.

Potential Research Directions

Occupancy-Based Energy Optimization

Use of PIR sensors, RFID, or computer vision to detect occupancy and adjust lighting accordingly.

Context-Aware Energy Management

Integration of weather data, calendar events, and user habits to optimize energy use intelligently.

Battery Storage and Renewable Integration

Managing indoor energy usage based on solar generation and battery status to reduce grid dependency.

Real-World Use Cases

Smart Homes

Automated lighting, climate control, and appliance scheduling to reduce bills and carbon footprint.

Hospitals

Energy optimization without compromising critical systems, with priority-based load management.

Smart Offices

Centralized energy dashboards, employee occupancy tracking, and AI-based meeting room scheduling.

Universities and Campuses

Smart classrooms and dormitories with learning-based energy control, reducing overall campus energy consumption.

Conclusion

The Smart Indoor Energy Optimization project using Internet of Things (IoT) technologies has successfully demonstrated how intelligent systems can significantly enhance energy efficiency in indoor environments. The project was designed with the objective of reducing energy consumption through automated monitoring and control of key environmental systems such as lighting, while ensuring user comfort and operational convenience.

Through the integration of smart sensors, actuators, microcontrollers, and connectivity protocols, the system continuously collected real-time data related to occupancy, temperature, humidity, light intensity, and other environmental variables. This data was processed using embedded logic and decision-making algorithms to dynamically adjust energy-consuming devices based on real-time conditions and user preferences. For example, lights were automatically turned off or optimized in unoccupied areas, while occupied zones received personalized environmental control.

The implementation showed a substantial reduction in unnecessary energy usage, particularly in scenarios involving irregular occupancy or fluctuating natural lighting. The system not only minimized energy waste but also contributed to better demand-side energy management. Moreover, the modular architecture of the system allows for easy scalability and integration with existing smart home or building automation platforms.

Another significant outcome of the project was the enhancement of user awareness and control. Through mobile or web-based interfaces, users could monitor energy usage patterns, receive alerts, and make informed decisions. This level of transparency fosters energy-conscious behavior and provides valuable insights for further optimization.

In conclusion, the project highlights the transformative impact of IoT in energy management, offering a practical solution to modern energy challenges. The results validate that IoT-driven indoor energy optimization is both technically viable and economically beneficial. Looking ahead, future improvements could include the integration of machine learning models to enable predictive control based on historical and contextual data, cloud-based analytics for large-scale deployment, and compatibility with renewable energy systems for an even more sustainable approach.

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- Focuses on IoT-based energy monitoring and control using sensors and microcontrollers like Arduino and ESP32.

  https://doi.org/10.1016/j.procs.2022.12.087

- Presents a system integrating smart plugs, sensors and machine learning for energy usage, prediction and control.

https://ieeexplore.ieee.org/abstract/document/8777547?utm_source=chatgpt.com

- Focuses on real-time monitoring of devices and applying optimization algorithms for energy savings.

  https://ieeexplore.ieee.org.com

- Research focusing on a decentralized management system using IoT and real big data to forecast, optimize, and schedule energy loads in a smart home, achieving significant energy cost reductions.

  https://doi.org/10.48550/arXiv.2502.06052

- Demonstrates integration of IoT and renewable energy with smart building controls in real environments.
  https://www.sensible-h2020.eu