Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 46 No. 10
October 2025

Design of Demand Side Management (DSM) Technology-based Domestic Lighting

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Abstract
Introduction: This article explores the implementation of demand-side management in domestic lighting through the Internet of Things (IoT). The objective is to enhance energy efficiency by dynamically controlling lighting systems based on real-time demand and user preferences. The study involves the design and deployment of IoT-enabled devices to monitor, analyze, and optimize lighting usage, contributing to a more sustainable and cost-effective residential energy consumption model. Key aspects include sensor integration, data analytics, and user interface development for seamless control and monitoring. The findings highlight the potential for significant energy savings and improved user experience in domestic lighting through IoT-based demand site management.
.**Objectives**: To design a physical usable prototype to demonstrate how a simple DSM technology can be achieved at home.

Methods: The proposed work aims to design and implement a prototype model that demonstrates Demand Side Management (DSM) in domestic lighting using Internet of Things (IoT) technology. The methodology adopted in this study consists of the following steps: (i) *Selection of IoT Control Platform:* A Wi-Fi enabled microcontroller board, such as ESP32 or NodeMCU, is selected to serve as the primary control unit. The inbuilt Wi-Fi capability ensures seamless connectivity with cloud servers and mobile devices for DSM implementation. (ii) *Programming of Control Logic:* The control board is programmed using the Arduino IDE with customized codes that define the DSM strategies. The program enables intelligent switching, load scheduling, and communication with the cloud server. (iii) *Circuit Design and Prototype Development:* An electronic circuit is designed to replicate domestic lighting loads. Light-Emitting Diodes (LEDs) are used to simulate household lighting, while relays are employed to represent actual switching devices. The control board, sensors, and actuators are integrated to develop a functional prototype. (iv) Simulation and Verification: The designed circuit and control logic are first tested using simulation tools such as Proteus or Thinkercad. Simulation helps verify circuit operation, connectivity, and DSM algorithm performance before physical implementation. (v) *Hardware Implementation:* Upon successful simulation, the prototype is realized at the hardware level using physical components. This step demonstrates the feasibility of the DSM-based lighting system in a real-time environment. (vi) *Cloud Integration and Remote Monitoring:* A cloud server (such as ThingSpeak, Firebase, or Blynk) is configured to host the IoT program. This enables remote monitoring and control of lighting loads via a web or mobile interface, thereby validating the DSM functionality.

Results: After reviewing and thoroughly testing the prototype, the results obtained were positive. The sample system performed reliably, and it was observed that the design can be scaled up depending on the capacity of the chosen control board.

The incorporation of **luminosity sensors** proved effective in detecting excess ambient light inside the house. This provided users with actionable information, helping them reduce unnecessary use of artificial lighting when natural light was sufficient. Similarly, the **home energy monitoring system** enabled real-time tracking of energy consumption. Unlike conventional household meter boxes, which are often ignored, the integration of energy data into a smartphone interface ensured that users could conveniently monitor and respond to their consumption patterns.

Overall, the prototype successfully demonstrated the ability of IoT and sensor-based systems to minimize energy wastage caused by user negligence in home lighting, while also promoting awareness of energy use.

Conclusions: This project has demonstrated the feasibility and effectiveness of applying Internet of Things (IoT) technology to demand-side management in domestic lighting. By integrating sensors, control algorithms, and cloud connectivity, the system dynamically adjusted lighting conditions based on real-time demand and user behavior. The results confirmed notable improvements in **energy efficiency** and **user awareness**, showing that IoT-based home lighting systems can reduce wastage and contribute to sustainable energy use. The combination of a **luminosity sensor** for ambient light detection and an **energy monitoring system** accessible via smartphone enhances both convenience and responsibility in household energy management. The successful implementation of this prototype highlights its potential scalability and broader application in modern households. Future work should focus on refining the design, improving user interfaces, and exploring large-scale deployment. This study represents a meaningful step toward creating smarter, energy-conscious homes through the fusion of IoT and DSM strategies.

Keywords: lighting, IOT, DSM.

1. Introduction

Power saving and power management are two popular terms in trend since the beginning of the 21st century. Both mean different things, but they are relatively similar in the sense that both aim to save the excess usage of energy all over the world.

Electricity is the energy used to power all kinds of electronics and electrical appliances. Electricity is generated in various ways. They are classified into two groups: conventional sources and non-conventional sources. Conventional sources of electricity are the majority in power production, and in India, fossil fuel-based conventional source of energy like coal, petroleum, etc., is the majority producer of electricity. This raises concerns all over the world since fossil fuel-based generation of electricity can result in the production of different kinds of waste materials, which are pollutants.

Demand side management (DSM) is, as the term says, it's the management of a certain product by the consumer. In this regard, DSM technology based on domestic lighting is related to the management of various electrical energy consumption on the side of ordinary citizens and consumers. While bigger establishments like businesses, universities, hospitals, etc. can install solar energy and biogas energy to reduce consumption of energy, average citizens are not able to do so and can only rely on energy provided by the state power distribution. So, managing the usage of electricity on the side of consumers can help in the reduction of bills, and consumption of unnecessary energy, and overall can impact in reduction of energy production on the production side.

2. Design

The required materials for the current design are: ESP32 WROOM Dev Module, Breadboard, Jumper cables, IR sensors, BH1750 Light Intensity Sensor, SCT-013-030 Non-invasive AC Current Sensor, ZMPT101B Single Phase Voltage Sensor, and Relay modules. Arduino IDE and Blynk are used as software.

Once the program is written in Arduino IDE, it's verified and uploaded to the ESP32 board. Virtual pins and a remote control board are created on the Blynk website and app. On the Blynk website, a control panel is built from which all the readings and controls can be accessed. In the smartphone app, a similar remote control is designed with various buttons, gauges, sliders, etc. The connection is established between the model and the web server.

This design can perform the following functions: **Automated Room Lighting:** Automated room lighting using two IR sensors. The importance of having two sensors is to make sure the system is not confused when multiple people enter or leave in random order.

Automated Bathroom Lighting: For the bathroom, a single sensor can be used to detect a presence in the bathroom, since bathrooms are designed to have a single user at a time.

LED Brightness Control: A remote control that can control the brightness of an LED bulb. This can be used to make sure a light is not too bright, and a lower brightness can always save more energy.

Light Intensity Sensor: A light intensity sensor to measure the ambient brightness of a room. This can help in making sure that the lights are not unnecessarily turned on while the room is bright enough from the sunlight or a single bulb.

Home Power Monitor: A power monitor with a voltage and current sensor that can monitor operating voltage, current consumption, and power consumption.

3. Circuit Diagram

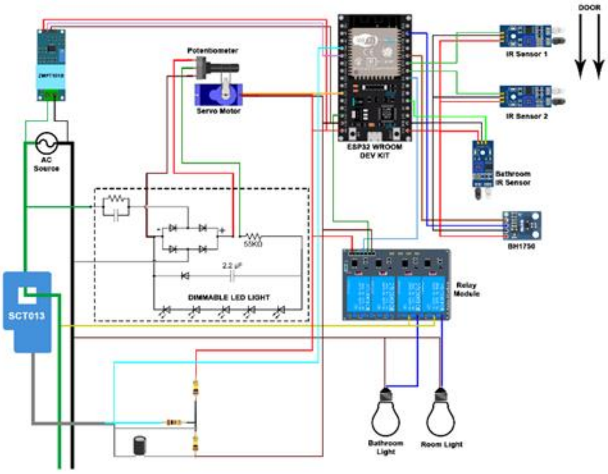

Fig. 1: Circuit diagram of the working model.

4. Working

The way the model works is as in the following:

Automated Home Lighting: For the house lighting, like a living room, bedroom, or just the whole building in general, an occupancy counter is set up. This is to make sure that the system doesn't get confused when multiple people are going in and out, and if one person were to just not leave the building for a while. Two IR sensors (assume sensor A and sensor B) are deployed. If the system detects a motion from A to B, the occupant counter will go up, and vice versa. To make sure the lights can be turned off manually, we can use, obviously, a physical switch, or a virtual switch in an app connected to the cloud server, which is for saving electricity during daytime and sleeping hours.

Automated Bathroom Lighting: For bathroom lighting or even ventilation fans, a simple IR sensor-based lighting is installed. This is because the bathroom is usually the one room where no person will enter lights off.

LED Brightness Control: A remote-controlled LED lamp with variable brightness. A slider control is set up, which is used to control a PWM output signal. This output signal is then supplied to a DC servo motor, which is used to control a potentiometer that controls the brightness of the LED lamp. This lamp is mostly for study rooms, workshop rooms, etc., where variable brightness can be useful according to the task at hand.

Light Intensity Sensor: A light intensity sensor using a BH1750 module to measure the ambient brightness of a room. BH1750 sends the data in lux (lux), which is then displayed on the app.

Home Power Monitor: A power monitor can be built using a voltage sensor and current sensor modules. The operating voltage and current consumed will be measured using the sensors, then the values can be formulated in the microprocessor to display an approximate power.

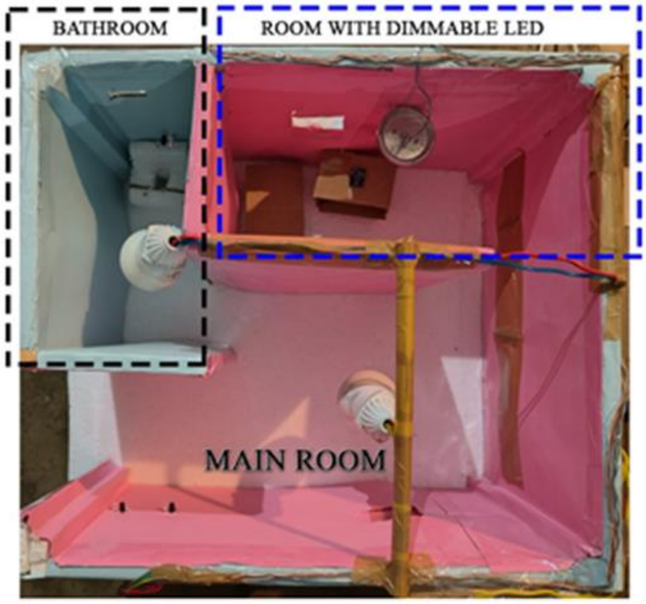

Fig. 2: The house model with three different rooms.

Fig.2 illustrates the model in an idle state, with all lights turned off. At this point, the Blynk remote interface appears as shown in Fig.3

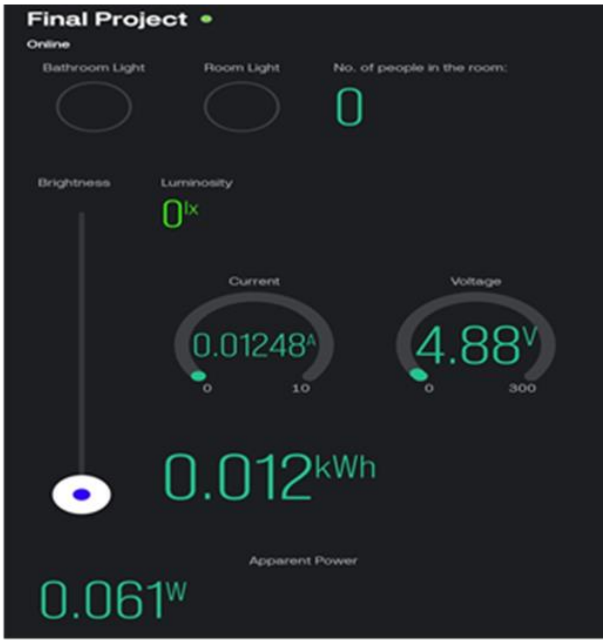

Fig. 3: Blynk remote interface in the idle state.

The results of each function have been explained in the following, along with figures.

(i) Automatic Home Lighting with Counter: In Fig. 4, we can observe that the light in the main room is on, and we see the counter (no. of the person in the room) showing a number. The light is on when the number is more than 0 (zero).

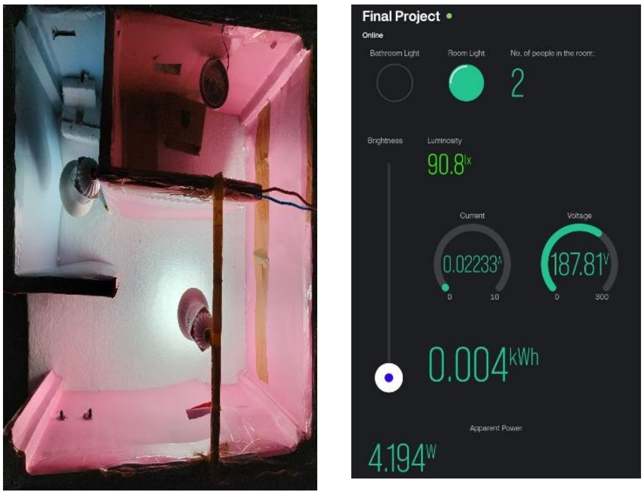

Fig. 4: Shows the main room light switched on (left). The Blynk remote interface, shown on the right, displays the counter and an activated indicator.

(ii) Automatic Bathroom Lighting: Here, the light turns on when there's a person in the bathroom, as in Fig. 5. The light stays off otherwise. The Blynk remote indicates the status of the light.

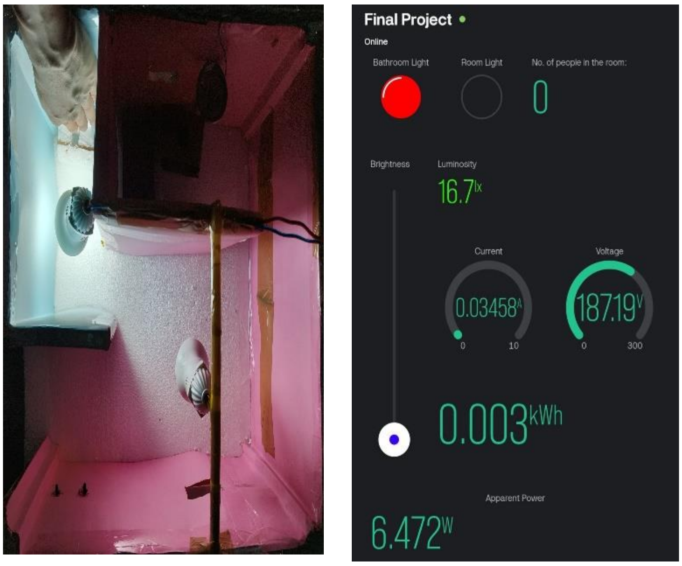

Fig. 5: The Bathroom light switched on (left), with the Blynk remote indicator responding accordingly (right).

(iii) LED Brightness Control: From Fig.6 to Fig.9, we can observe that the brightness of the LED installed in the room with a dimmable LED can be controlled using the slider in the Blynk remote control.

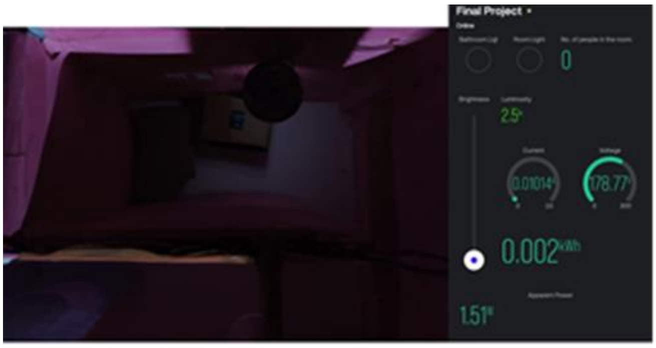

Fig. 6: Shows the slider adjusted to its lowest position (right), resulting in the light appearing very dim (left).

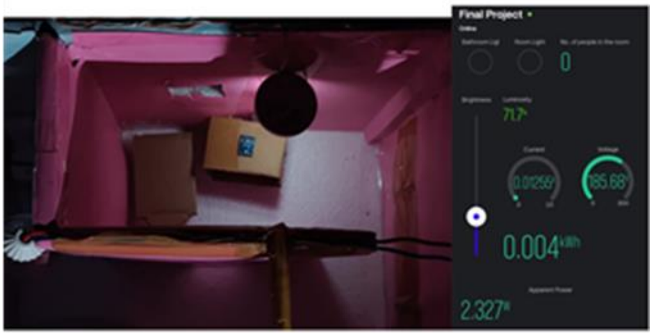

Fig. 7: The slider increased by approximately 30% (right), resulting in greater light brightness (left).

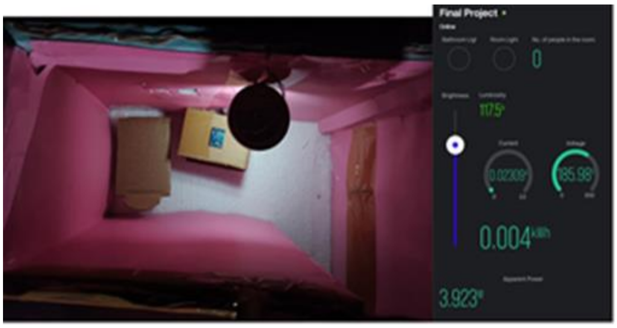

Fig. 8: The Slider set to approximately 75% (right), with the light nearing full brightness (left).

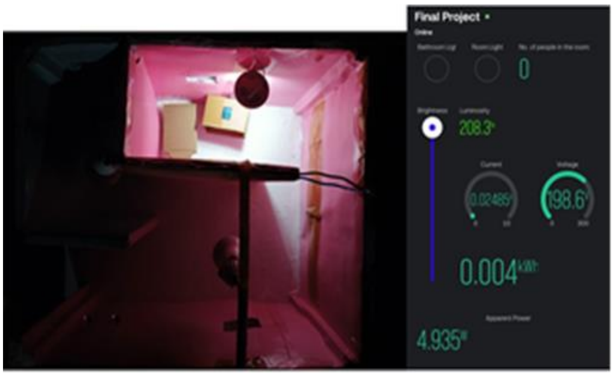

Fig. 9: Shows the slider moved to its highest setting (right), resulting in the bulb reaching full brightness (left).

(iv) Luminosity sensor: The BH1750 is installed under the variable brightness LED bulb (Fig. 10). This is to showcase the sensitivity of the sensor. As seen in Figs. 6 to 9, the luminosity changes as the brightness changes.

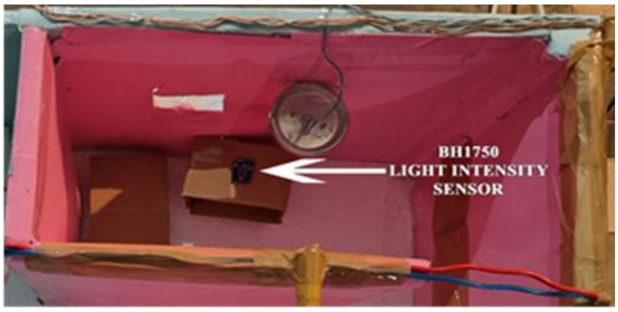

Fig. 10: The BH1750 Luminosity Sensor is installed under the dimmable LED bulb.

(v) Home power monitor: ZMPT101B and SCT013 sensors have been installed to measure voltage and current, respectively. Then the measured voltage and current are used to give apparent power and kWh measurement on the Blynk remote. In Fig. 11, we can observe the change in power and current according to the usage of the appliances.

Fig. 11: Illustrates how power consumption rises as more appliances are used (left to right).

5. Flowchart

The following flowchart Fig.12 simplifies the functions and workings of the system.

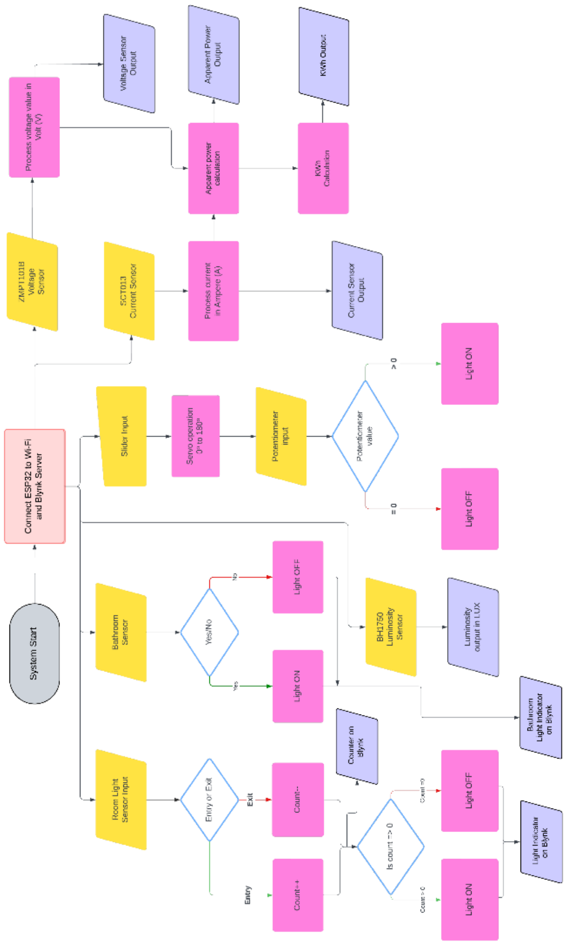

Fig. 12: Flowchart detailing the different processes of the system

6. Conclusion

Following extensive testing, the prototype delivered positive results and demonstrated scalability within the limits of the board's capacity. The system integrates IoT and sensor technologies to develop an energy-efficient home lighting solution aimed at reducing wastage from careless usage.

The luminosity sensor provides real-time ambient light data, enabling users to minimize unnecessary illumination, while the home energy monitoring system offers immediate feedback on electricity consumption via a smartphone interface. Unlike conventional household meter boxes that are often ignored, this approach ensures energy usage information is accessible and actionable, encouraging responsible consumption.

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