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Smart Lighting Systems for Optimized Energy Usage (Automatic Street Lighting Systems)

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Abstract- Energy-efficient lighting systems can benefit from ambient light sensors that adjust artificial lighting based on natural light. This helps save energy and improves comfort by providing the right amount of light throughout the day. The key technology includes advanced sensors, control algorithms, and system designs that enable real-time lighting adjustments for efficient performance in different conditions. By using these sensors, smart buildings can save energy and reduce waste, supporting sustainable practices. Future research aims to improve sensor accuracy and better integrate these systems with IoT platforms for smarter, more responsive lighting solutions.
***Keywords*:** smart lighting system; rule-based heuristic; energy consumption; recommendation system.

1. INTRODUCTION

The growing global emphasis on sustainability and energy conservation has led to significant innovations in smart lighting systems, particularly in indoor environments such as offices, educational institutions, and homes. A major portion of energy usage in buildings is attributed to electric lighting, thereby increasing the demand for energy-efficient and personalized lighting solutions [1].
In this context, Smart Light Emitting Diode (LED) systems have emerged as a promising technology, offering both high luminous efficacy and long operational life [2].
Smart LED lighting, when combined with dimming control and daylight integration, can effectively optimize energy use without compromising the illumination needs of occupants [3,4].
Recent studies have shown that implementing smart lighting can result in up to 50% energy savings [5–7].

These savings are achieved through strategies that automatically adjust the lighting intensity based on environmental factors and user behavior [8]. Specifically, daylight data and weather conditions play a crucial role in enhancing the control mechanisms of such systems [9,10].
To manage and analyze vast amounts of data for lighting control, IoT-based solutions are widely adopted. These include the use of sensors such as motion, occupancy, photocells, lux meters, and temperature sensors, which are integrated with microcontrollers like Arduino and NodeMCU for real-time processing and communication [11,12].
These systems can intelligently regulate luminous flux through dimming algorithms, contributing significantly to energy reduction and enhanced comfort [13,14].
Moreover, adaptive dimming strategies have been developed to ensure the luminous environment aligns with users' preferences while minimizing energy wastage. Techniques such as pulse-width modulation (PWM) and automatic calibration based on ambient light levels have demonstrated substantial improvement in operational efficiency [15,16].

Researchers have also highlighted the importance of self-calibrating systems that can adjust to new conditions without manual intervention [17].

High-frequency dimming and dynamic control based on lux values and occupancy data allow for further energy savings. Studies indicate that such methods can reduce energy usage by more than 30% [18].

A variety of sensor configurations and intelligent feedback mechanisms have been tested in real-time environments, revealing how user comfort can be balanced with ecological responsibility [19,20].

Despite these advances, current systems often lack real-time monitoring, personalized user notifications, and integrated feedback systems for optimizing brightness and power usage. To bridge this research gap, we propose a real-time smart lighting control system that integrates daylight factors, user preferences, and sensor data to adaptively manage indoor lighting environments [21].

This system employs advanced motion and daylight sensors to dynamically adjust lighting levels based on occupancy and natural light availability. It also incorporates user preferences to optimize lighting for specific tasks and times of day. Additionally, real-time energy monitoring and recommendation notifications are included to provide users with feedback, behavioral insights, and actionable tips for reducing energy usage [22].

Our proposed framework also facilitates data logging, enabling continuous learning and adaptation to environmental changes, which makes the system more autonomous and intelligent. By integrating sensing, control, user feedback, and energy analytics, this system aims to improve the efficiency, usability, and eco-friendliness of smart indoor lighting systems [23].

2. LITERATURE REVIEW

Review of Related Work

2.1 Self-Calibrating Smart Lighting Systems

Aussat et al. (2022) proposed a power-efficient, self-calibrating smart lighting system capable of adjusting brightness based on environmental conditions. The system eliminates the need for manual recalibration by leveraging adaptive control algorithms and smart sensors. Its scalability and real-time adaptability make it suitable for diverse environments, from homes to commercial buildings, demonstrating considerable energy savings.

2.2 Wireless Power Transfer with Color Control

Zhou et al. (2018) introduced a wireless LED lighting control method that combines power transmission and communication through a single inductive link. The brightness is managed via pulse width modulation, while color control is achieved using a compact time-division multiplexing protocol. This solution is cost-effective, flexible, and practical for applications requiring minimal wiring and high aesthetic appeal.

2.3 Smart Technology in Healthcare Lighting

Fong et al. (2023) focused on power optimization in smart nursing homes, identifying lighting, HVAC, and kitchen zones as major energy consumers. A predictive control model was employed, achieving a 10% improvement in energy efficiency while maintaining safety and comfort. The study demonstrates the potential of tailored smart lighting systems in healthcare and assisted living facilities.

2.4 Smart Street Lighting with Motion Sensing

Mouaadh et al. (2022) developed a motion-sensor-based smart street lighting system to reduce public lighting energy consumption. The system activates full brightness only when motion is detected and dims otherwise, enabling forward signaling to illuminate upcoming zones. This approach achieved up to 50% energy savings and proved to be both cost-effective and highly efficient in real-world trials.

2.5 LiFi-Based Smart Lighting for Intelligent Buildings

Aljewari et al. (2021) explored LiFi (Light Fidelity) technology integration with smart lighting systems. Using standard LEDs with RJ45 converters, the authors implemented a cost-efficient and scalable setup for secure, high-speed data transmission and lighting control. This innovation merges lighting and communication infrastructure, enhancing building automation and operational control.

2.6 User Behavior and Energy Efficiency

Gentile (2022) emphasized the role of user behavior in lighting energy consumption. Despite technological advancements, user habits significantly influence energy usage. The study highlighted key behavioral dimensions such as dimming preferences, interface usability, and feedback mechanisms. Results indicate that behavioral interventions could halve energy consumption, underscoring the importance of human-centered design in smart lighting systems.

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2. METHODOLOGY

This project follows a simple and practical approach to creating an energy-efficient lighting system using ambient light sensors. The first step was to identify the problem with traditional lighting systems, which often waste electricity because they don't adjust based on natural light. To solve this, we designed a system that uses an ambient light sensor (BH1750) and a microcontroller (Arduino Nano) to automatically control artificial lighting depending on the surrounding light conditions.

The system is built with three main parts: a light sensor, a processing unit, and a lighting control mechanism. The sensor continuously measures natural light levels and sends the data to the microcontroller. Based on the readings, the controller adjusts the brightness of the lights using MOSFET-based PWM control. Initially, SCRs were considered, but they did not perform well, so we switched to MOSFETs, which work more efficiently and allow smoother dimming.

To build the system, we carefully selected the right components, designed a compact PCB, and ensured a stable power supply. The software for the system was written using Arduino IDE, with an embedded algorithm that automatically controls the lighting. If there is enough natural light, the system dims or turns off the artificial lights. When natural light is low, the system increases the brightness as needed.

Once the system was assembled, we tested it in both simulations and real-world conditions. The results showed that it responded quickly to changes in light and significantly reduced electricity usage compared to regular lighting systems. After testing, we made further improvements by optimizing the PCB design and fine-tuning the power management.

Looking ahead, we plan to integrate IoT technology so that the system can be controlled remotely and used in smart buildings. The design is flexible and can be applied to homes, offices, and industries. By automating lighting based on real-time light conditions, this project provides a simple yet effective way to save energy and promote sustainability.

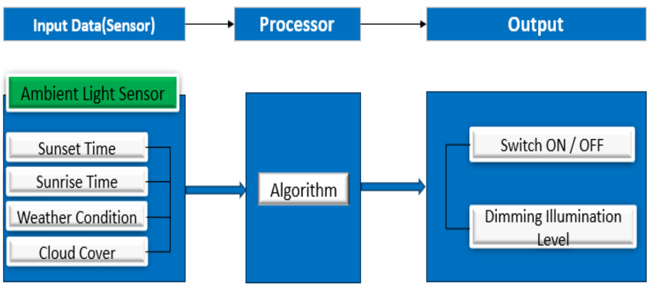

Fig. 1 Condition Block Diagram

3. BLOCK DIAGRAM

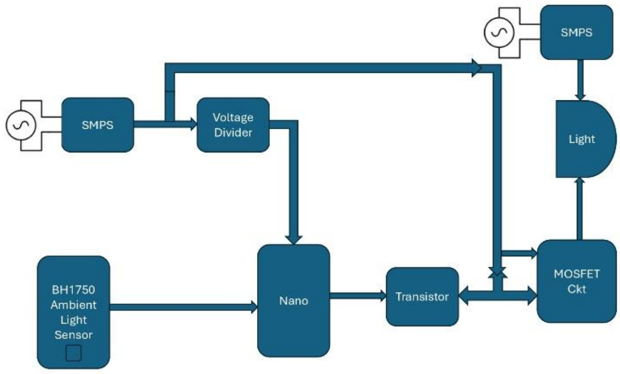

Fig. 2 Block Diagram

4. CIRCUIT DIAGRAM

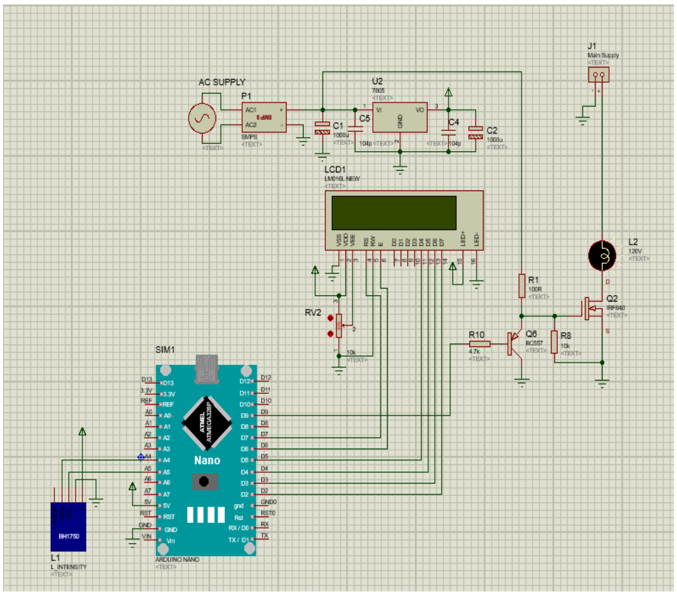

Fig. 3 Circuit Diagram

5. Working of the Light

The Optimized Energy Usage in Lighting System operates by intelligently adjusting the brightness of street lights based on the availability of natural light. The process begins with a 230V AC supply, which is converted into 12V DC using an SMPS (Switched-Mode Power Supply). This 12V DC supply is then regulated by a voltage divider or a voltage regulator circuit, which steps it down to 5V DC. The 5V DC is essential for powering the Arduino Nano, LCD display, and ambient light sensor.
The ambient light sensor (LDR or BH1750) continuously monitors the natural light intensity. This sensor sends real-time data to the Arduino Nano, which processes the input according to a pre-programmed algorithm. Based on the sensor readings, the Arduino determines whether

artificial lighting is required and, if so, to what extent.
During nighttime or in low-light conditions, when natural light is insufficient, the Arduino triggers the MOSFET-based switching circuit to provide 100% brightness to the lighting system. However, when natural light starts increasing, the system dynamically adjusts the brightness using PWM (Pulse Width Modulation) signals. For instance, if the sensor detects that 50% natural light is available, the system reduces the artificial lighting to 50%, ensuring that the total illumination remains at an optimal level while minimizing energy wastage.
The use of a MOSFET driver circuit enables efficient current control, allowing for smooth brightness transitions and power optimization. By ensuring that artificial lighting complements the available natural light, the system helps in reducing energy consumption while maintaining adequate illumination levels.

6. CONCLUSION

This project offers an intelligent, efficient, and sustainable lighting solution that optimally balances natural and artificial light sources. By leveraging real-time ambient light sensing, MOSFET-based PWM control, and a structured PCB design, it sets a new standard for smart lighting automation. Future research and iot integration will further enhance its adaptability, making it a pioneering step in energy-efficient lighting technology.

7.FUTURE SCOPE

This project can be enhanced with iot integration, AI-driven optimization, and wireless connectivity for smarter automation. Future advancements may include solar power compatibility, advanced sensors, and mobile app control for real-time monitoring. Additionally, Wi-Fi technology can enable both lighting and data transmission. With these upgrades, the system can be widely adopted in smart homes, offices, industries, and cities, promoting sustainable and intelligent lighting solutions.

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