Energy-Efficient Led Lighting System for Smart Buildings

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***Abstract*—Energy consumption in buildings can be reduced by making lighting responsive to actual occupancy and available natural light. Conventional lighting systems often depend on manual switching and may remain ON when a room is empty or when sufficient daylight is available. This paper presents an Energy-Efficient LED Lighting System for Smart Buildings using an LED bulb or LED strip, Arduino Uno, PIR motion sensor, LDR (Light Dependent Resistor), LED driver or relay module, resistors, breadboard, jumper wires and a suitable 5V/12V power supply. The PIR sensor detects human presence, while the LDR detects surrounding daylight. Arduino Uno processes these sensor signals and controls the LED lighting through the driver or relay interface. The proposed system is intended to switch or regulate artificial lighting according to room occupancy and daylight conditions. The approach can reduce unnecessary lighting operation, improve convenience and provide a low-cost platform for smart-building applications. Prototype measurements of power consumption, operating time and illumination should be used to quantify the final energy savings. The system can be further extended using IoT connectivity, data logging, mobile monitoring and automatic dimming.**

***Index Terms*—LED lighting, Arduino Uno, PIR sensor, LDR, smart building, energy efficiency, automatic lighting control.**

I. INTRODUCTION

Lighting is an essential electrical load in residential, commercial and institutional buildings. Traditional lighting systems are commonly operated through manual switches or fixed schedules. Such approaches do not continuously respond to whether a room is occupied or whether natural daylight is sufficient. Unnecessary operation increases energy consumption and operating cost.

LED technology offers high efficiency, long service life and easy electronic control. Smart control can provide additional savings by using sensors to operate lighting only when required. Occupancy sensing can detect human presence, while daylight sensing can determine whether artificial lighting is necessary. Combining both signals allows a controller to make a more suitable lighting decision.

This project develops a simple prototype based on Arduino Uno, PIR and LDR sensors. The objective is to demonstrate how low-cost components can be combined to create an automated LED lighting system suitable for smart-building applications.

II. PROBLEM STATEMENT

Conventional lighting may remain ON in unoccupied areas and may operate unnecessarily when adequate daylight is available. Manual control also depends on user behaviour. Therefore, there is a need for a simple, low-cost and automatic lighting system that detects occupancy and daylight and controls LED lighting according to actual requirements.

III. OBJECTIVES

- To design an energy-efficient LED lighting system for smart-building applications.
- To detect human presence using a PIR motion sensor.
- To detect surrounding daylight using an LDR.

- To process sensor signals using Arduino Uno.
- To automatically control an LED bulb or LED strip through a driver/relay interface.
- To reduce unnecessary lighting operation and support energy conservation.
- To provide a low-cost prototype that can be expanded for IoT and building automation.

IV. LITERATURE REVIEW

Research in smart lighting has shown that energy-efficient LED luminaires can achieve additional energy savings when combined with occupancy and daylight-responsive controls. Pandharipande and Caicedo reviewed smart indoor lighting systems and discussed occupancy- and daylight-based control approaches [1]. Aussat, Rosmanis and Keshav investigated a self-calibrating smart lighting system that adapts to daylight and occupancy, demonstrating the potential of adaptive lighting control [2]. Dikel et al. studied high-resolution sensor controls for LED lighting and reported additional savings associated with occupancy sensing and daylight harvesting in an office environment [3]. Zou et al. proposed an occupancy-driven lighting control system using wireless sensing for smart buildings [4]. Garg and Bansal also investigated occupancy sensors as a means of reducing lighting energy consumption [5].

Based on these studies, the proposed student prototype applies the same general principle in a simpler hardware configuration: detect occupancy, detect daylight, process both signals in a controller, and operate LED lighting only when required.

V. PROPOSED SYSTEM

The proposed system consists of an LED bulb or LED strip, Arduino Uno, PIR motion sensor, LDR, LED driver or relay module, resistors, breadboard, jumper wires and a 5V/12V power supply. An optional LCD can display lighting status or sensor values.

Component	Purpose	Function in Proposed System
LED Bulb / LED Strip	Provides lighting	Produces artificial illumination
Arduino Uno	Main controller	Processes PIR/LDR signals and generates the lighting-control output
PIR Motion Sensor	Detects presence	Identifies whether a person is present in the monitored area
LDR	Detects daylight	Provides an indication of surrounding light level
LED Driver / Relay Module	Controls LED safely	Interfaces the controller with the LED load
Resistors	Limits current	Protects components and supports sensor/circuit connections
Breadboard	Circuit assembly	Provides a convenient platform for prototype connections
Jumper Wires	Electrical connections	Connects sensors, controller and other components
5V/12V Power Supply	Power source	Supplies the required electrical power to the circuit
LCD Display (optional)	Displays information	Shows lighting status or sensor values

VI. SYSTEM ARCHITECTURE

The proposed signal flow is:

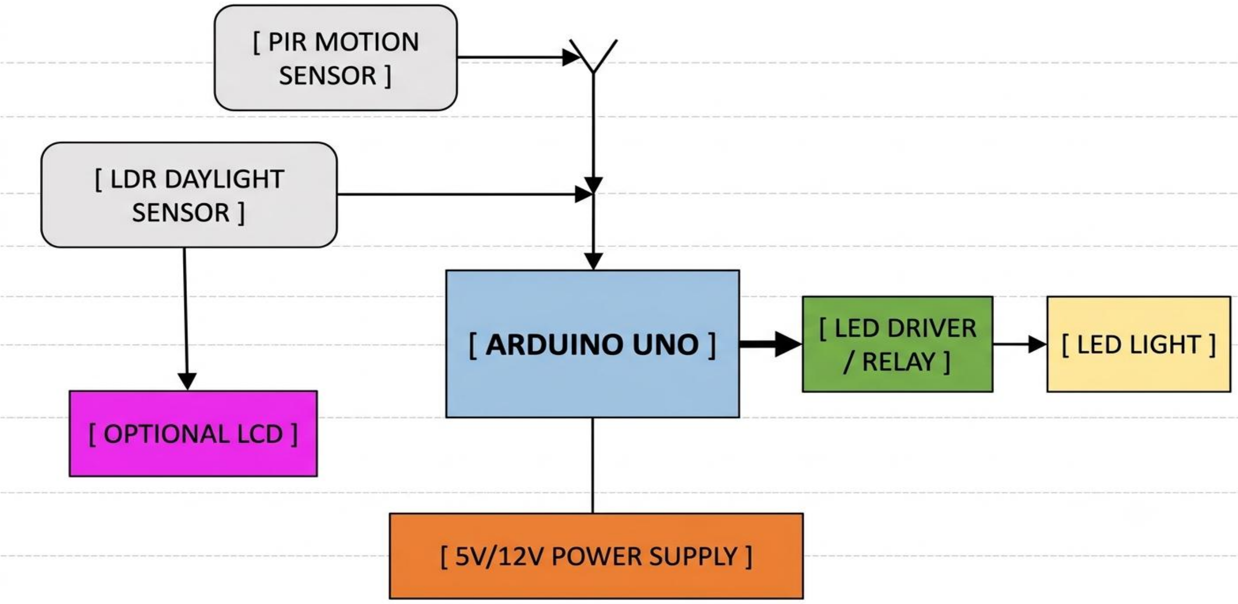

Fig: System Architecture

VII. METHODOLOGY

The system begins by supplying power to the Arduino, sensors and lighting interface. The PIR sensor monitors the area for human movement or presence. The LDR provides a signal related to the surrounding light level. Arduino Uno reads both inputs and applies the programmed control logic. If the area is unoccupied, the LED is switched OFF or kept at its minimum permitted state. If a person is detected, the controller checks the daylight condition. When daylight is sufficient, artificial lighting can remain OFF or be reduced if dimming hardware is available. When daylight is insufficient, the controller activates the LED through the driver or relay module.

For an ON/OFF prototype, the decision can be expressed as: Occupancy detected AND daylight below the selected threshold → LED ON. Otherwise → LED OFF. The actual threshold values should be selected and tested experimentally for the final prototype.

VIII. WORKING PRINCIPLE

1. The Arduino Uno initializes the PIR sensor, LDR and LED-control output.
2. The PIR sensor detects movement/presence in the monitored area.
3. The LDR senses the surrounding light level.
4. Arduino compares the sensor conditions with the programmed thresholds.
5. If no person is detected, the LED is switched OFF.
6. If a person is detected and daylight is low, the LED is switched ON.
7. If a person is detected but daylight is sufficient, the LED remains OFF in the basic ON/OFF implementation.
8. The controller continuously repeats the sensing and control process.

IX. EXPERIMENTAL SETUP AND TESTING

The prototype should be tested under controlled conditions to determine whether the proposed system reduces unnecessary lighting operation. The following test cases are recommended.

For a fair comparison, measure the conventional/reference lighting system and the smart system for the same operating period. Record voltage, current, power and operating duration. If possible, measure illumination in lux at representative locations. Energy saving can be calculated as:

Energy Saving (%) = [(E_reference − E_smart) / E_reference] × 100.

X. RESULTS AND DISCUSSION

The expected benefit of the proposed system is reduced LED operating time when the room is unoccupied or when adequate daylight is available. The actual energy-saving percentage must be obtained from measurements of the completed prototype and should not be assumed. The final paper should include a table of measured readings and a graph comparing reference lighting with sensor-controlled lighting.
Performance is expected to depend on PIR detection range, LDR placement, daylight variation, selected threshold values, LED rating, room layout and user behaviour. Proper sensor placement and calibration are therefore important for reliable operation.

XI. ADVANTAGES

- Automatic lighting control.
- Reduced unnecessary lighting operation.
- Efficient LED-based illumination.
- Low-cost and easy-to-build prototype.
- Reduced dependence on manual switching.
- Can be adapted to classrooms, laboratories, offices and other rooms.
- Can be expanded to IoT-based smart-building systems.

XII. LIMITATIONS

- PIR sensors primarily respond to movement and may not reliably detect a completely stationary person.
- LDR readings depend on placement, shadows and surrounding light conditions.
- An ON/OFF prototype provides less precise control than a dimming system.
- Energy savings depend on actual occupancy and daylight patterns.
- The prototype requires appropriate electrical isolation and a correctly rated driver/relay for the LED load.

XIII. FUTURE SCOPE

- IoT connectivity for remote monitoring and control.
- Mobile/web dashboard for energy consumption.
- Automatic LED dimming using PWM or a suitable dimming driver.
- Cloud-based data logging.
- Multiple lighting zones with independent sensors.
- Adaptive or AI-based lighting control using occupancy patterns.
- Integration with building-management systems and renewable energy sources.

XIV. CONCLUSION

This paper presents an Energy-Efficient LED Lighting System for Smart Buildings using Arduino Uno, PIR motion sensing and LDR-based daylight sensing. The proposed system automatically controls LED lighting according to occupancy and surrounding daylight. The concept is simple, low-cost and suitable for demonstrating smart-building energy management at prototype scale. The final performance should be established using actual measurements of power, energy and, where applicable, illumination. Future improvements such as IoT monitoring, automatic dimming and intelligent control can make the system more suitable for larger smart-building applications.

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