

**REAL TIME ENERGY-EFFICIENT SMART LIGHTING SYSTEM**

**BY**

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**BENIN CITY, EDO STATE, NIGERIA.**

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**A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF  
COMPUTER SCIENCE, FACULTY OF PHYSICAL SCIENCES,  
UNIVERSITY OF BENIN, BENIN CITY**

**IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD  
OF A BACHELOR OF SCIENCE (B.Sc.) DEGREE IN COMPUTER  
SCIENCE**

**FEBRUARY 2025**

## **CERTIFICATION**

This is to certify that this project work was carried out by **CHEGWE FAVOUR** with Matriculation Number **PSC2003795** under my supervision. It is adequate and satisfactory, both in scope and content, for the award of Bachelor of Science (B.sc) Degree in Computer Science of the University of Benin.

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**MR I.E OBAYAGBONA**

Project Supervisor

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**DATE**

## **APPROVAL**

This project work is hereby approved in partial fulfillment of the requirements for the award of Bachelor of Science (B.Sc.) Degree in Computer Science from the University of Benin.

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**PROF. GODSPower .O. Ekuobase, PhD**  
(Head of Department)

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**DATE**

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## **DEDICATION**

I dedicate this project to the almighty God who has given me the strength and might to carry out this project successfully and to everyone who ensured that this project to be a success.

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## **ABSTRACT:**

The growing demand for energy conservation and sustainable technologies has highlighted the need for intelligent systems to optimize energy consumption in various domains, including lighting. This paper presents the design and implementation of a real-time energy-efficient smart lighting system that integrates advanced sensors, wireless communication, and adaptive control strategies. The system employs motion sensors, ambient light sensors, and time-based algorithms to dynamically adjust lighting levels based on environmental conditions, occupancy, and user preferences. The smart lighting system is capable of reducing energy wastage by automatically dimming or turning off lights in unoccupied spaces, while ensuring adequate illumination when needed. Additionally, the system incorporates real-time monitoring and data analytics to track energy consumption patterns, providing actionable insights for further optimization. Experimental results demonstrate the effectiveness of the proposed system in reducing energy consumption, enhancing user comfort, and contributing to sustainable building management practices. The system offers a scalable solution for residential, commercial, and industrial applications, addressing both environmental and economic goals of energy efficiency.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 BACKGROUND STUDY

Smart lighting systems have significantly evolved in recent years. Driven by advancements in technology and a growing emphasis on energy efficiency and sustainability, these systems offer a range of benefits, including reduced energy consumption, enhanced comfort, and improved security.

Smart lighting systems are increasingly being integrated with other smart home devices, such as thermostats, security systems, and voice assistants. This integration allows for seamless control and automation of various home functions. The development of more sophisticated sensors, including occupancy sensors, light sensors, and color sensors, has enabled more precise and responsive lighting control.

AI and ML algorithms are being applied to smart lighting systems to optimize energy consumption, predict user behavior, and personalize lighting experiences. Research is being conducted to explore the impact of lighting on human health and well-being. This has led to the development of smart lighting systems that can adjust color temperature and intensity to support circadian rhythms and enhance productivity.

The widespread adoption of energy-efficient LED lighting has significantly reduced energy consumption. Smart lighting systems further optimize energy usage by automatically adjusting lighting levels based on occupancy and ambient light conditions.

LiFi, or Light Fidelity, uses visible light to transmit data, offering high-speed, secure, and energy-efficient communication. It can be integrated with smart lighting systems to provide additional functionalities, such as real-time data analytics and remote control. Solar-powered smart lighting systems are becoming increasingly popular, especially in remote areas and outdoor applications. These systems harness solar energy to power the lights, reducing reliance on grid electricity.

Advanced algorithms and sensors enable dynamic lighting control, where the lighting system automatically adjusts to changing environmental conditions and user preferences. This can optimize energy usage and improve user comfort. Smart lighting systems can be integrated with building automation systems to optimize energy consumption for the entire building. This can lead to significant energy savings and improved building performance.

As technology continues to advance, we can expect to see even more innovative and sophisticated smart lighting systems in the future. These systems will play a crucial role in creating sustainable and comfortable living and working environments.

## **1.2 STATEMENT OF PROBLEM**

Traditional lighting systems are inefficient, often remaining on even when not needed, leading to unnecessary energy consumption and higher costs. While energy-efficient technologies like LEDs have been introduced, most systems still lack the ability to adapt to real-time factors such as occupancy and natural light. This results in wasted energy, especially in commercial and residential buildings. There is a clear need for a **smart lighting system** that automatically adjusts based on real-time conditions to optimize energy usage and reduce waste.

### **1.3 AIM AND OBJECTIVE**

The aim of this project is to design and implement a Real-Time Energy-Efficient Smart Lighting System that automatically adjusts lighting based on occupancy, ambient light levels, and real-time data to optimize energy consumption, reduce electricity costs, and promote environmental sustainability.

#### **Objectives of the Project**

The objectives of the project are as follows:

1. **System Design:** Develop a comprehensive design for the smart lighting system, including hardware (sensors, controllers) and software components (energy optimization algorithms).
2. **Data Collection and Analysis:** Gather and analyze real-time data on occupancy patterns and ambient light levels to enable intelligent lighting adjustments.
3. **Sensor Integration:** Select and integrate appropriate sensors (e.g., motion sensors, light sensors) for real-time monitoring and control.
4. **Energy Optimization Algorithm:** Design and implement algorithms to adjust lighting dynamically, ensuring energy efficiency without compromising lighting quality.
5. **Real-Time Monitoring:** Implement a system to monitor energy usage and environmental conditions in real-time for continuous optimization.
6. **User Interface Development:** Create an intuitive user interface for controlling, configuring, and monitoring the smart lighting system.

7. Testing and Evaluation: Test the system in a real-world environment to evaluate its effectiveness in reducing energy consumption and improving lighting quality.
8. Comparison with Conventional Systems: Compare the energy efficiency and performance of the smart lighting system with traditional, non-adaptive lighting solutions.
9. Environmental Impact Assessment: Ensure the system reduces energy consumption and carbon footprint, contributing to environmental sustainability.
10. Documentation and Reporting: Document the design, implementation, and testing processes to provide a comprehensive report on the system's effectiveness and potential applications.

#### **1.4 SIGNIFICANCE OF STUDY**

Studying a Real-Time Energy-Efficient Smart Lighting System in a Nigerian university is significant as it advances the field of energy management and smart technologies. This project enhances the understanding of energy-efficient systems, promotes sustainability, and encourages innovation in smart infrastructure. It prepares students for future careers in IoT, energy conservation, and automation. The study also fosters creativity in addressing real-world energy challenges, contributing to environmental sustainability, and supports national development by reducing energy consumption. Additionally, it opens opportunities for funding, industry collaborations, and the adoption of smart technologies across Nigerian institutions and businesses.

## **1.5 SCOPE OF STUDY**

The scope of studying a **Real-Time Energy-Efficient Smart Lighting System** in a Nigerian university includes the development of energy-efficient algorithms, sensor integration, and system automation. It covers applications in residential, commercial, and industrial buildings, focusing on energy optimization through real-time data monitoring. The study explores user interfaces for system control, cost-saving analysis, and the environmental impact of smart lighting solutions. It also addresses ethical considerations, the potential for large-scale deployment, and resource optimization. This research offers valuable innovation opportunities in energy conservation, sustainability, and smart technologies across various academic and societal sectors.

## **1.6 LIMITATIONS OF STUDY**

Limitations of studying a Real-Time Energy-Efficient Smart Lighting System in a Nigerian university include limited access to localized data on energy consumption patterns, resource constraints for hardware and sensor integration, and a lack of expertise in advanced energy management technologies. Ethical concerns related to privacy in smart systems, challenges in the integration of different hardware components, and user acceptance of automated lighting systems may also hinder implementation. Overcoming these limitations will be crucial for ensuring the successful deployment and effectiveness of the system.

## **1.7 GLOSSARY OF TERMS**

This section defines key terms related to the study of a Real-Time Energy-Efficient Smart Lighting System to provide clarity for readers unfamiliar with the technical concepts.

1. Smart Lighting System: A lighting system that uses sensors, automation, and connectivity to optimize energy use, improve comfort, and enhance functionality by adjusting lighting based on occupancy, ambient light, and user preferences.
2. Real-Time System: A system that processes data and responds to inputs instantly, ensuring adjustments are made based on current conditions without delay
3. Occupancy Sensor: A device that detects the presence or absence of people in a space, automatically turning lights on or off to save energy
4. Ambient Light Sensor: A sensor that measures natural or artificial light levels, allowing the system to adjust artificial lighting to complement available light.
5. Energy Optimization Algorithm: A set of rules or calculations used to adjust lighting in a way that minimizes energy use while maintaining desired lighting conditions.
6. LED (Light Emitting Diode): An energy-efficient lighting technology that consumes less power and lasts longer than traditional bulbs.
7. LiFi (Light Fidelity): A wireless communication technology that uses visible light to transmit data, offering high-speed and energy-efficient connectivity.
8. IoT (Internet of Things): A network of interconnected devices that communicate and exchange data, enabling smart lighting systems to integrate with other smart devices.
9. Dynamic Lighting Control: The ability of a lighting system to automatically adjust brightness, color, and other parameters in response to changing environmental conditions or user preferences.
10. User Interface (UI): The means by which users interact with the system, such as through smartphones or touchscreens, to control and monitor lighting settings.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Introduction of Real-Time Energy-Efficient Smart Lighting Systems:

Real-time energy-efficient smart lighting systems represent the forefront of modern energy conservation technologies. These systems integrate IoT, AI, and machine learning (ML) to enable dynamic, automated control of lighting in various environments. Unlike traditional lighting systems, which rely on fixed schedules or manual adjustments, smart lighting is adaptive and can respond to a variety of conditions, such as occupancy, ambient light, time of day, and even weather patterns. Through these intelligent adjustments, smart lighting systems not only ensure optimal user comfort but also contribute significantly to reducing energy consumption.

The major components of a smart lighting system include:

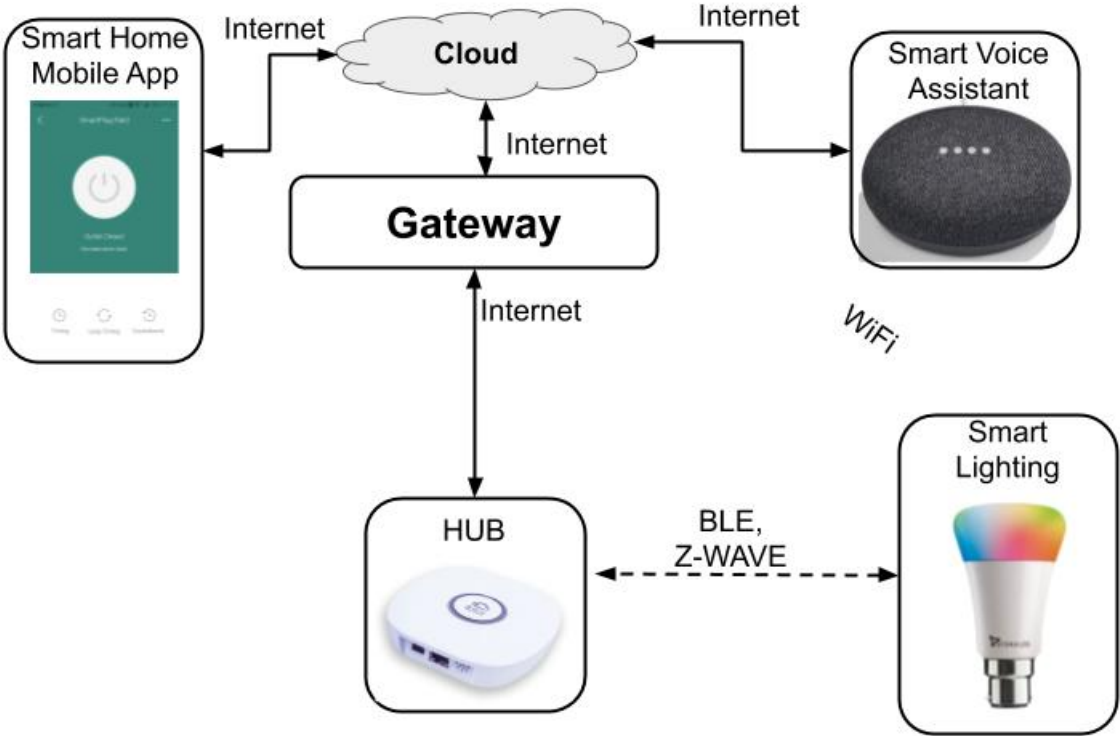
**Smart bulbs:** These often include LED technology, offering high efficiency and longevity compared to traditional bulbs.

**Sensors:** Light, motion, occupancy, and environmental sensors gather real-time data, enabling the system to adjust lighting levels dynamically.

**Connectivity:** IoT protocols such as Wi-Fi, Zigbee, or Bluetooth Low Energy (BLE) enable seamless communication between smart devices.

**Centralized control systems:** Often via mobile apps or cloud-based platforms, these control systems allow for remote and automatic adjustments of the lighting settings based on real-time data and predefined preferences.

The energy-saving potential of smart lighting systems is immense. According to IEA (2018), smart lighting systems can save up to 30% of total lighting energy in cities, especially when combined with advanced control algorithms and real-time optimization. This is vital as urban centers face escalating energy demands and rising concerns over environmental impacts.



**Fig 1. Diagram of Smart Lighting System Components**

## 2.2 Early Developments of Smart Lighting Systems

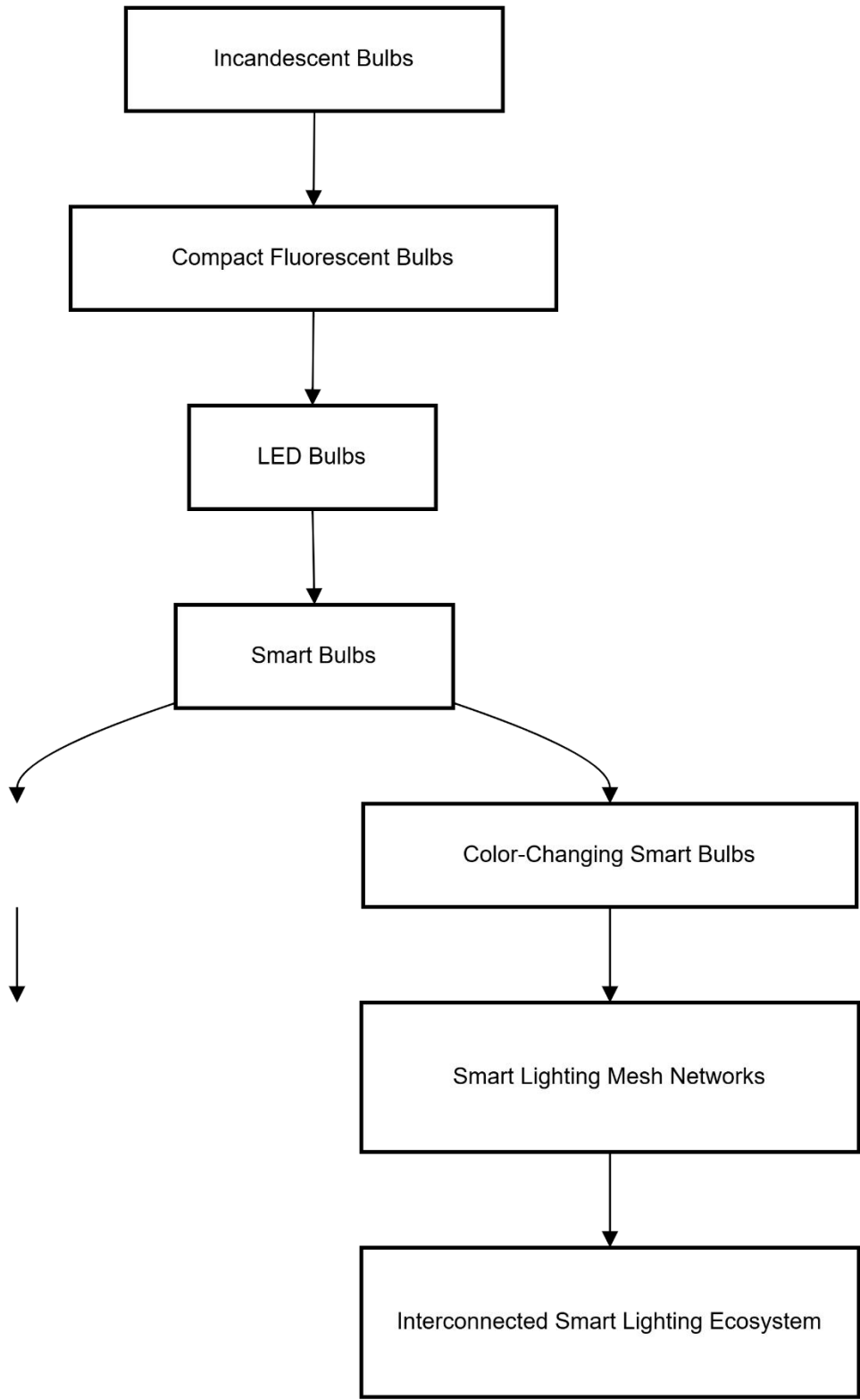
The journey toward modern smart lighting began with basic manual lighting systems, which were either on or off with minimal regulation. Early innovations focused on improving energy efficiency, beginning with CFLs (compact fluorescent lamps) and later LED technology. These new lighting technologies offered substantial energy savings, reducing electricity consumption and extending the lifespan of bulbs. LEDs, in particular, have played a key role in transforming the lighting landscape, offering a significantly lower wattage consumption compared to traditional incandescent bulbs.

However, despite their energy efficiency, LEDs were still often controlled manually or via simple timers. A significant leap forward came in the 1990s with the introduction of motion sensors. These sensors enabled automatic lighting activation based on presence detection, ensuring that lights were only on when needed. This was particularly beneficial in spaces with low occupancy, such as bathrooms, hallways, and closets.

The real transformation came in the early 2000s, with the rise of smartphones and the introduction of wireless connectivity protocols such as Wi-Fi and Bluetooth. These allowed users to remotely control lighting through mobile apps or web interfaces. Zigbee, Z-wave, and other mesh networking protocols began to enable smart home ecosystems, where lighting was integrated with other home automation devices, such as thermostats and security cameras.

However, it was not until the advent of IoT and cloud technologies in the 2010s that smart lighting systems truly began to evolve into the intelligent, energy-efficient solutions that we see today. These advancements allowed lighting to be integrated with cloud-based platforms, enabling real-time analysis of data from sensors, including motion, ambient light, and

temperature sensors. As a result, lighting could now be dynamically adjusted based on external and internal factors, such as time of day, weather conditions, and room occupancy.



**Fig 2. Flowchart of Smart Lighting Evolution**

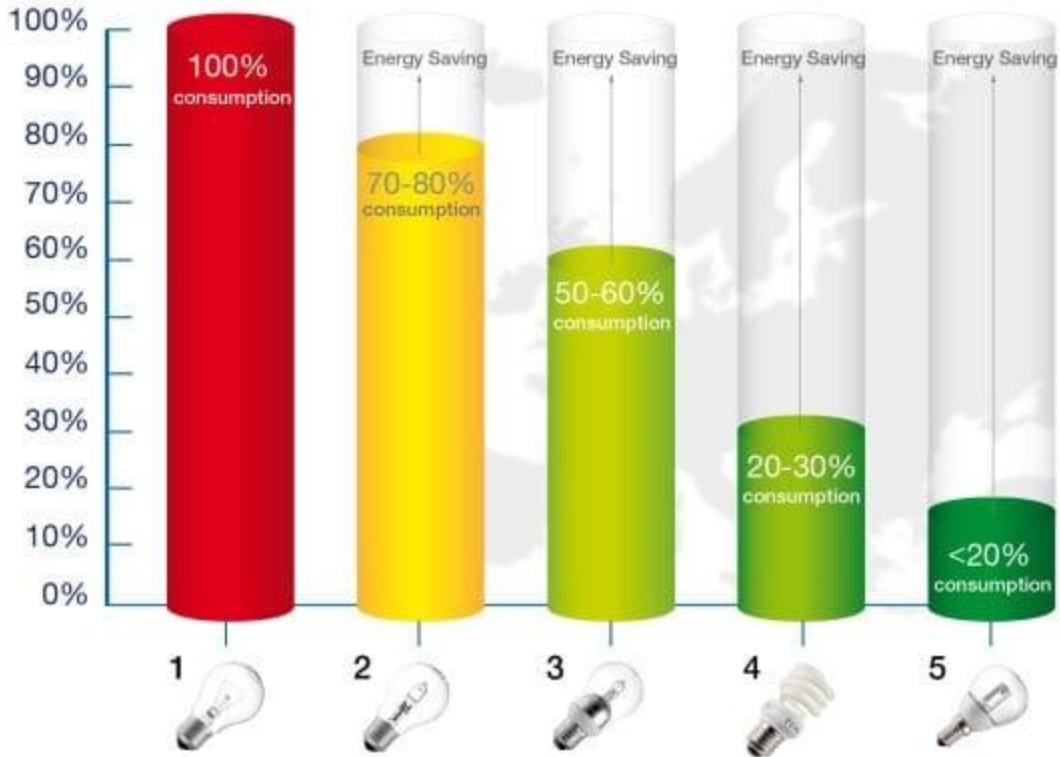
## **2.3 Evolution of Energy-Efficient Smart Lighting**

### **2.3.1 The Role of LED Technology in Smart Lighting Systems**

The development of LED technology marked a pivotal moment in energy-efficient lighting. LEDs consume significantly less energy than incandescent bulbs and have a much longer lifespan. These advantages alone make them a more sustainable choice for lighting. LEDs are now widely used in smart lighting systems, where their efficiency is further enhanced by sensors and automated controls.

Unlike conventional bulbs that operate at a fixed brightness level, smart LEDs can adjust their luminance based on real-time data. In combination with smart controllers (either embedded in the fixture or via external systems), LEDs can dim, brighten, or even change color temperatures according to specific environmental needs. These adjustments lead to energy savings as lights are only used at necessary times and at appropriate intensities.

## Energy Saving vs. Energy Consumption



- 1: Conventional incandescent bulbs
- 2: Improved incandescent bulbs  
(class C of the energy label, halogen lamp with xenon gas filling)
- 3: Improved incandescent bulbs  
(class B of the energy label, halogen lamp with infrared coating)
- 4: Compact fluorescent lamps (CFLs)
- 5: Light-emitting diodes (LEDs)

Source: European Commission

**Fig 3. LED vs. Traditional Bulb Energy Consumption Comparison (Graph)**

### 2.3.2 The Integration of IoT and Cloud Computing

The integration of IoT technology into lighting systems revolutionized their functionality. Smart lighting systems began using networked sensors and cloud computing platforms to process and analyze data in real-time. This data-driven approach allowed for more granular control over lighting operations.

In this new era, lighting systems became highly adaptive. Light sensors could adjust the intensity based on the amount of natural light in the room, while motion sensors would turn the lights off automatically when a room was empty. Occupancy sensors detected human presence and adjusted the lighting based on predefined settings or the time of day, further improving energy efficiency.



**Fig 4. Illustration of IoT Integration with Lighting (Networked Devices)**

### **2.3.3 Introduction of Machine Learning and Artificial Intelligence**

In the past decade, the integration of machine learning (ML) and artificial intelligence (AI) has dramatically enhanced the performance of smart lighting systems. These systems now learn from historical data, including user behavior, environmental changes, and seasonal patterns. By predicting lighting needs based on accumulated data, AI-powered lighting becomes increasingly more efficient and personalized.

For example, AI can predict which areas of a building will need lighting at specific times of day. It can also consider external data, such as weather forecasts or local events, to adjust lighting dynamically before changes occur. This predictive capability reduces energy waste, as lights are only turned on or adjusted when necessary, and at the right intensity.

## **2.4 Role of Artificial Intelligence in Smart Lighting**

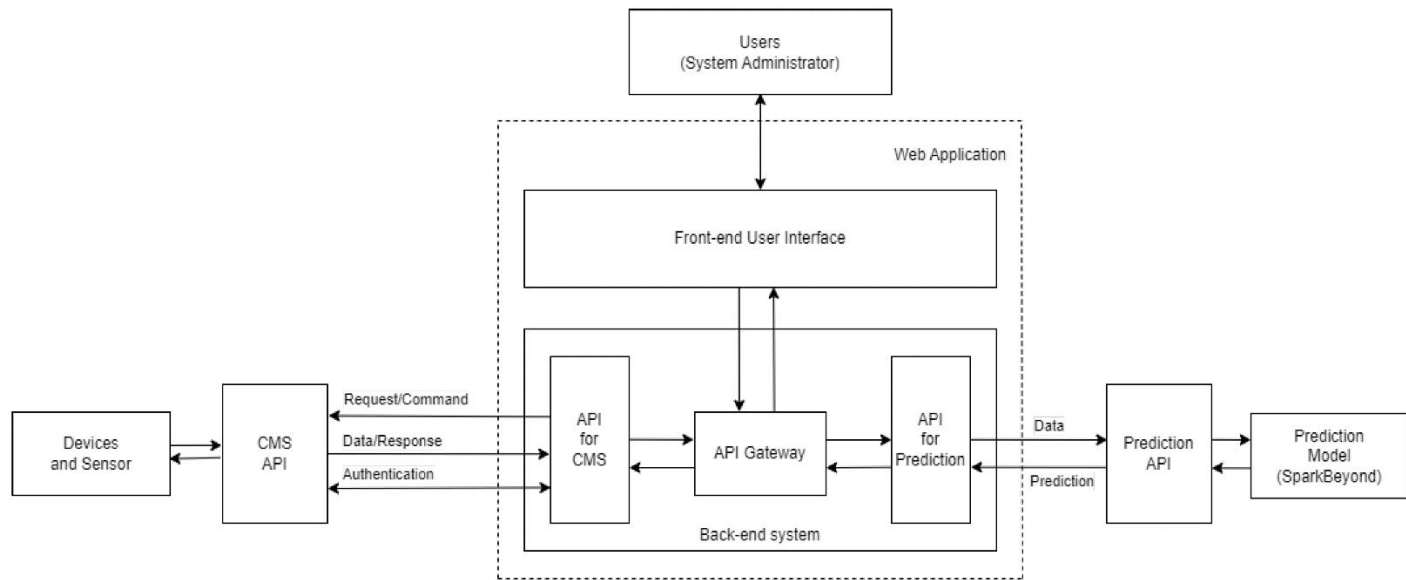
The role of artificial intelligence (AI) in smart lighting systems goes beyond just the automated turning on or off of lights. AI integrates with machine learning algorithms to offer highly responsive and predictive systems. This means the system is not merely reacting to current conditions but is able to forecast future needs based on historical data, user preferences, and even external inputs such as weather forecasts.

### **2.4.1 Predictive Lighting Systems**

With AI, smart lighting systems can anticipate future needs. For example, a lighting system in a commercial office could predict when employees are likely to arrive and begin working, and it could adjust the lighting to a comfortable level before they even enter. Similarly, in residential

settings, AI-powered lighting systems learn the patterns of a household, automatically adjusting to their schedule without requiring user intervention.

In public spaces, such as street lighting, AI can adjust the lighting based on traffic flow, pedestrian activity, or even weather conditions. These systems can increase or decrease light intensity to enhance safety or reduce energy consumption when traffic or footfall is low.



**Fig 5. AI-Powered Lighting Adjustment (Predictive System Visualization)**

### 2.4.2 Energy Optimization through AI

AI also facilitates energy optimization in real-time. For instance, AI systems can continuously adjust the intensity of lighting based on time of day, occupancy, or external lighting conditions. This allows for a highly efficient energy use model where lights are only illuminated when needed, and at the appropriate level.

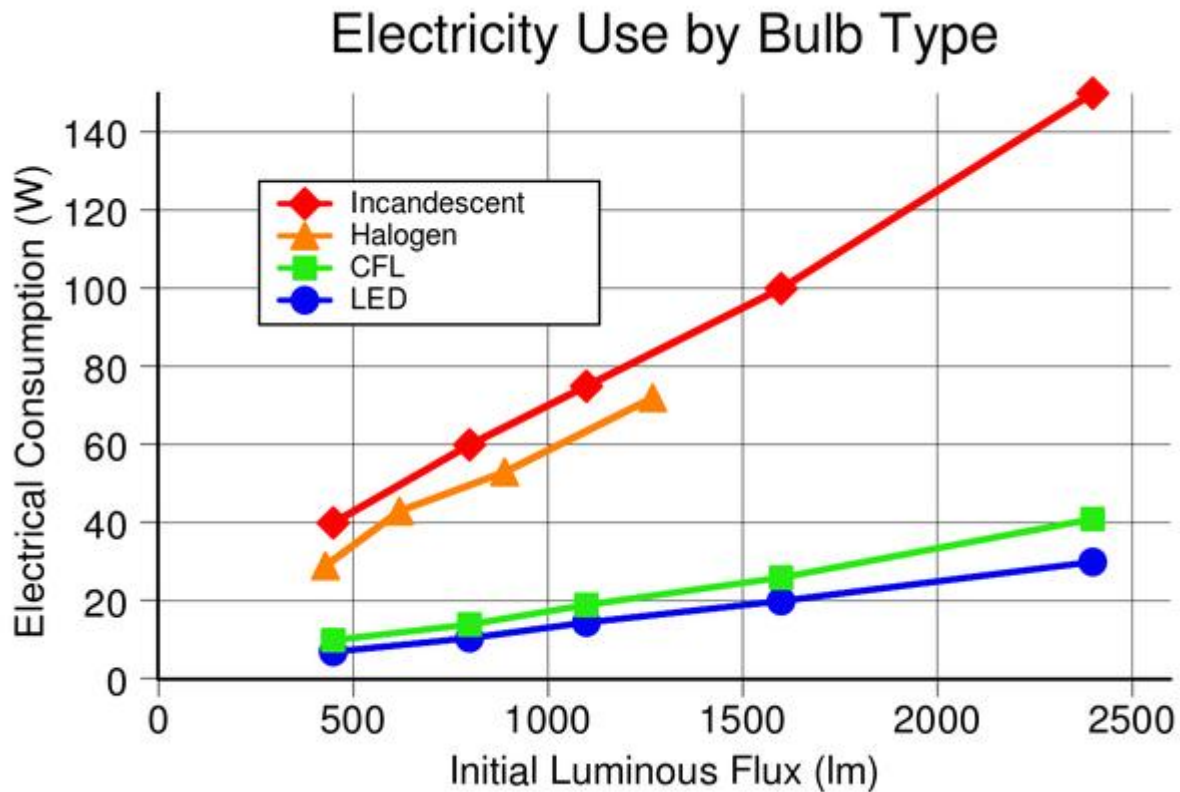
Moreover, AI can help monitor energy consumption patterns and adjust settings across the lighting network to optimize energy savings over time. It can even alert users when areas are consuming more energy than necessary, providing recommendations for improving energy usage.

## **2.5 Evaluation Metrics and Challenges in Smart Lighting Systems**

The effectiveness of smart lighting systems can be measured using several key performance indicators (KPIs) that assess their impact on energy savings, user comfort, and system responsiveness.

### **2.5.1 Energy Efficiency Metrics**

One of the most crucial metrics for evaluating smart lighting systems is energy efficiency. This involves analyzing the reduction in electricity usage resulting from the implementation of smart controls such as motion sensors, ambient light sensors, and occupancy detection. For example, studies have shown that incorporating motion sensors in commercial buildings can reduce lighting energy use by up to 60% (US Department of Energy, 2016). Smart lighting systems can further optimize energy savings by adjusting to external environmental factors, such as daylight availability or seasonal changes.



**Fig6. Energy Savings Comparison Graph**

### 2.5.2 User Comfort and Customization

Another important metric is user comfort. Smart lighting systems can be designed to meet user preferences, adjusting color temperatures and brightness levels according to individual needs. The comfort level can be assessed by analyzing user feedback, such as satisfaction surveys, and understanding how lighting contributes to the user's overall well-being. For example, personalized lighting systems can adapt to the user's activities (e.g., dimmer lights for movie watching, bright lights for reading).

### **2.5.3 System Responsiveness**

A highly effective smart lighting system must be responsive to changing conditions. This includes the ability to detect occupancy, respond to ambient light levels, and adjust the lighting intensity almost instantly. The latency of the system, or the delay in responding to changes, can significantly affect its efficiency. Ideally, the system should detect changes in real-time and adjust the lighting accordingly without noticeable lag.

## **2.6 Ethical Considerations in Smart Lighting Systems**

As AI-powered and IoT-based lighting systems become more prevalent, there are significant ethical concerns that need to be addressed. These concerns primarily revolve around privacy, data security, and user autonomy.

### **2.6.1 Data Privacy and Security**

Smart lighting systems collect vast amounts of data, including user behavior, occupancy patterns, and environmental conditions. This data is used to optimize energy consumption, but it can also be vulnerable to cyberattacks. Unauthorized access to the data could compromise the privacy of individuals or organizations. Ensuring robust data encryption, user consent protocols, and secure storage is essential to protect users' privacy.

### **2.6.2 User Autonomy and Control**

As smart lighting systems become increasingly autonomous through the use of AI, there may be concerns about the reduction in user control. While automation can enhance efficiency and comfort, it may also make users feel that they have lost control over their environment. Finding

the right balance between automation and user control is crucial to maintaining satisfaction and autonomy.

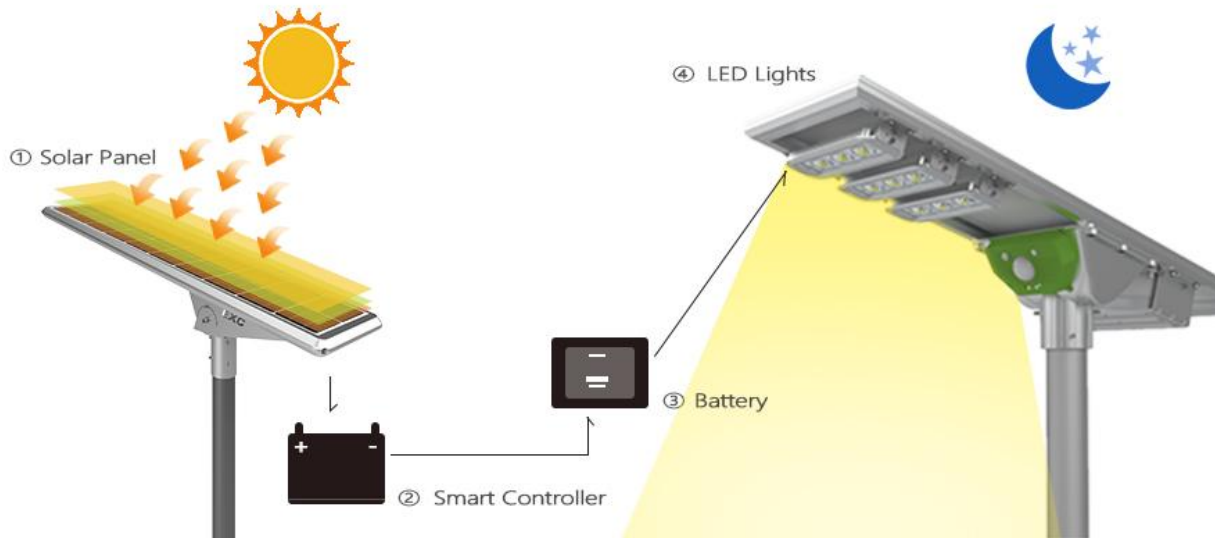
## **2.7 Sustainability and Environmental Impact of Smart Lighting Systems**

Sustainability is one of the key drivers behind the development and adoption of smart lighting systems. The energy-efficient nature of smart lighting directly contributes to reducing **carbon emissions**, as it minimizes electricity consumption. Smart lighting systems are not just about technological innovation but also about reducing the environmental footprint of lighting operations.

### **2.7.1 Integration with Renewable Energy Sources**

A growing trend in the development of smart lighting systems is their integration with **renewable energy sources**, such as **solar power**. These systems can be designed to operate independently of the power grid by using solar panels to charge the lighting components, further reducing the carbon footprint of lighting in public and private spaces.

Smart streetlights, for instance, can use **solar-powered panels** combined with battery storage to function at night, making them both energy-efficient and self-sustaining. This integration supports the shift toward **net-zero energy buildings** and **smart cities**. In these environments, smart lighting systems contribute to the **circular economy**, as they utilize renewable energy and have long lifespans, reducing waste.

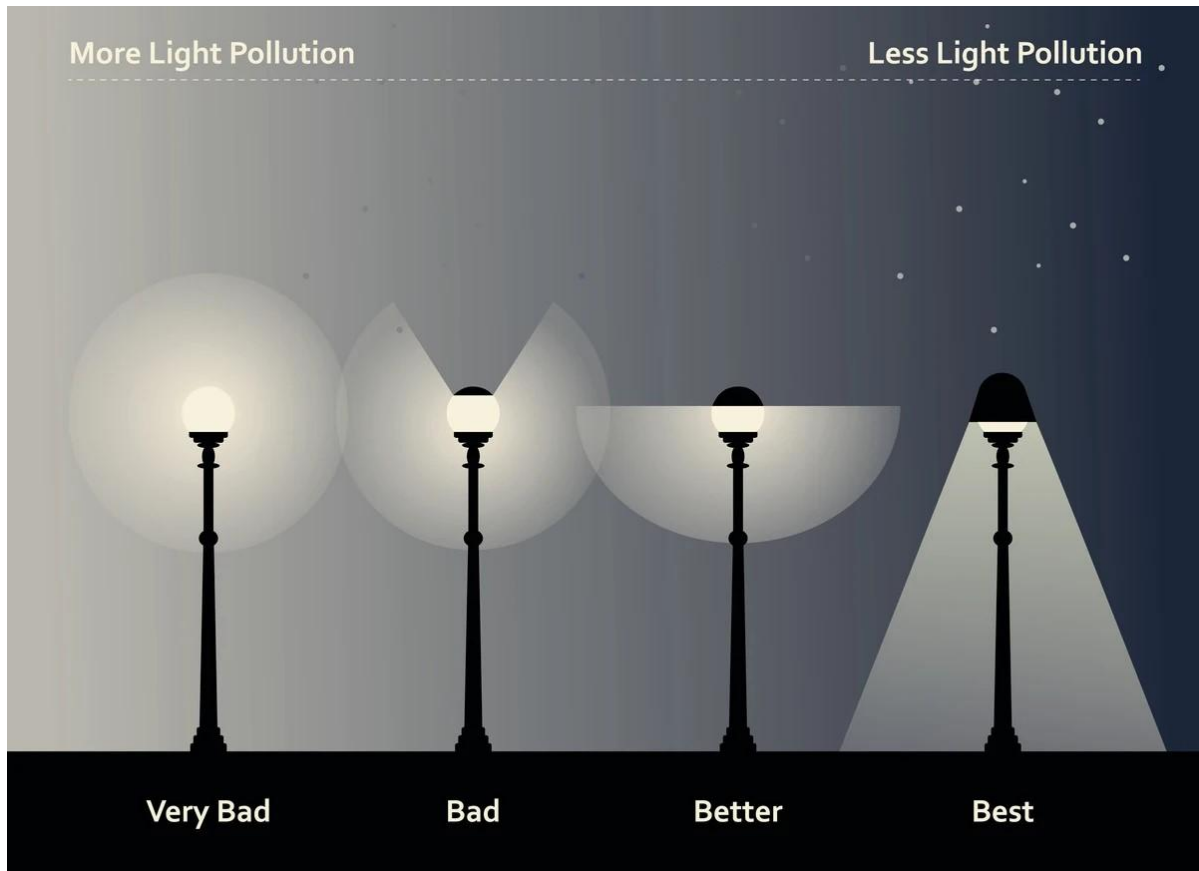


**Fig7. Solar-Powered Smart Streetlight example**

### 2.7.2 Reduction in Light Pollution

Another environmental benefit of smart lighting is its potential to reduce **light pollution**. Traditional streetlights often waste energy by emitting light indiscriminately, which can disrupt ecosystems and hinder astronomical observations. Smart lighting systems, on the other hand, can be designed to adjust light intensity according to demand, using **motion sensors** to activate lights only when needed. Furthermore, **directional lighting** can minimize light spill, ensuring that illumination is focused only on the necessary areas, reducing unnecessary light exposure to the environment.

By managing lighting more precisely, smart lighting systems not only conserve energy but also minimize negative ecological impacts, such as disrupting nocturnal wildlife or wasting unnecessary lighting in urban spaces.



**Fig8. Diagram of Light Pollution Reduction**

## 2.8 Global Perspectives and the Adoption of Smart Lighting

The adoption of smart lighting systems is occurring at different rates across the world, driven by technological advances, policy frameworks, and regional challenges. **Developed countries** tend to be early adopters of smart lighting, particularly in urban areas, where the need for energy efficiency and sustainability is most pressing.

### 2.8.1 Smart Cities and Urban Infrastructure

As cities grow larger and more complex, the need for intelligent, energy-efficient solutions becomes even more critical. **Smart cities**, which leverage IoT technologies, are increasingly integrating smart lighting systems to improve both energy efficiency and quality of life for their

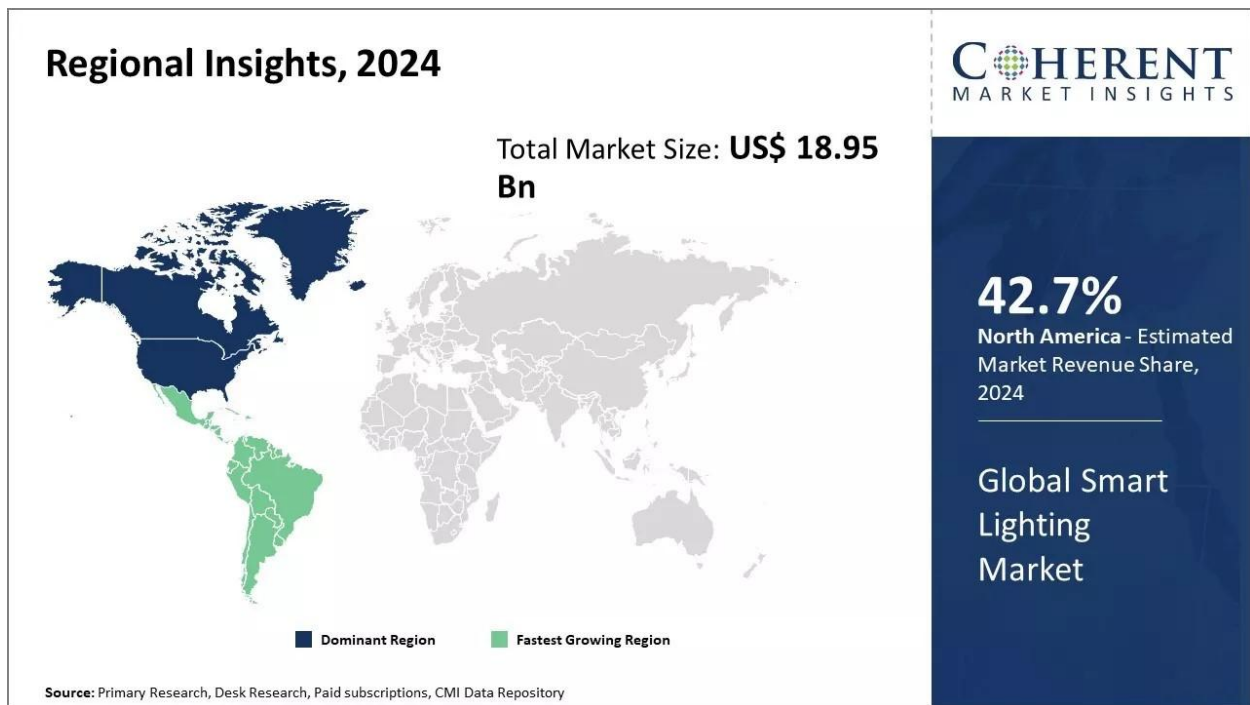
citizens. For instance, cities like **Barcelona**, **New York**, and **London** have invested in smart lighting systems to optimize public lighting, reduce energy costs, and improve safety.

Cities in emerging economies are also beginning to explore smart lighting, particularly as they aim to balance urbanization with environmental sustainability. In **India**, for example, smart street lighting projects have been rolled out in select cities to address both **energy poverty** and the growing need for sustainable infrastructure in fast-developing urban centers.

### **2.8.2 Regional Barriers and Adoption Challenges**

While there are clear benefits to smart lighting systems, barriers to adoption persist, especially in **developing countries**. These barriers include high initial costs, lack of local expertise, and inadequate infrastructure for **IoT** and **cloud services**.

However, with **global sustainability goals** pushing for energy-efficient solutions, it is expected that over time, technologies will become more affordable and accessible. Furthermore, international collaborations and technological transfer programs can assist in accelerating the adoption of smart lighting in emerging markets.



**Fig9. Map of Global Smart Lighting Adoption**

## 2.9 Interoperability and Standardization Challenges

For smart lighting systems to reach their full potential, they must be capable of seamlessly integrating with a variety of other smart technologies, such as **smart thermostats, security cameras, and energy management systems**. However, **interoperability** remains a challenge in the current landscape, as different manufacturers use different standards for **wireless communication protocols** (e.g., **Zigbee, Z-Wave, Wi-Fi, and Bluetooth**).

### 2.9.1 The Need for Standardized Protocols

The lack of universal standards for smart lighting and IoT devices leads to compatibility issues, limiting the scalability and efficiency of these systems. Inconsistent communication protocols and proprietary technologies can create silos within smart home ecosystems, reducing the overall functionality and performance of smart lighting networks.

Efforts are underway to address these concerns, with initiatives such as the **Open Connectivity Foundation (OCF)** and **Thread Group** working to develop standards for interoperability among IoT devices. Standardization will likely play a critical role in promoting wider adoption and enhancing the integration of smart lighting systems across different applications.

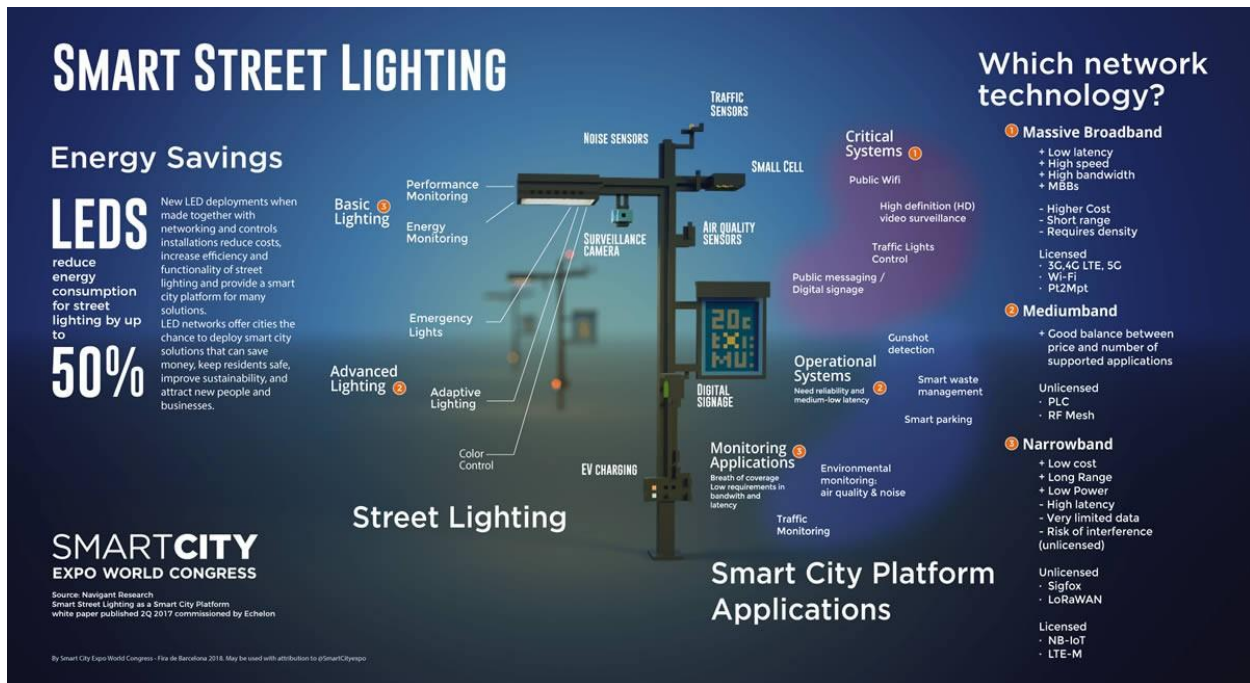
## **2.10 Future Prospects: The Role of 5G and Edge Computing in Smart Lighting**

The future of smart lighting is closely tied to advancements in **5G networks** and **edge computing**. These technologies are expected to significantly enhance the capabilities of smart lighting systems, enabling even faster response times, better scalability, and more sophisticated features.

### **2.10.1 5G Networks and Smart Lighting**

The introduction of **5G networks** promises to enable **faster data transmission speeds** and **lower latency**, which are crucial for the real-time operation of smart lighting systems. With 5G, smart lighting systems can respond to dynamic conditions with near-instantaneous updates, providing more precise control over lighting in real-time. This is particularly important for **large-scale urban lighting systems** where data must be processed and acted upon quickly.

5G could also enable greater **integration of augmented reality (AR)** and **virtual reality (VR)** in smart lighting systems. For instance, AI-powered systems might adjust lighting based on the specific tasks being performed, such as providing task lighting for office work or creating ambient lighting for entertainment.



**Fig10. 5G Networks and Smart Lighting**

## 2.10.2 Edge Computing and Real-Time Data Processing

**Edge computing** involves processing data closer to where it is generated (i.e., at the "edge" of the network) rather than sending it to centralized cloud servers. This reduces latency and enables faster response times, which are essential for real-time decision-making in smart lighting systems.

For example, smart lighting systems using **edge computing** can detect occupancy, ambient light levels, and environmental conditions and immediately adjust the lighting, without waiting for cloud-based data processing. This enables highly responsive and efficient lighting management in real-time, reducing the load on cloud infrastructures and improving overall system performance.



**Fig11. Edge Computing and Real-Time Data Processing infographic**

## CHAPTER THREE

### SYSTEM ANALYSIS AND DESIGN

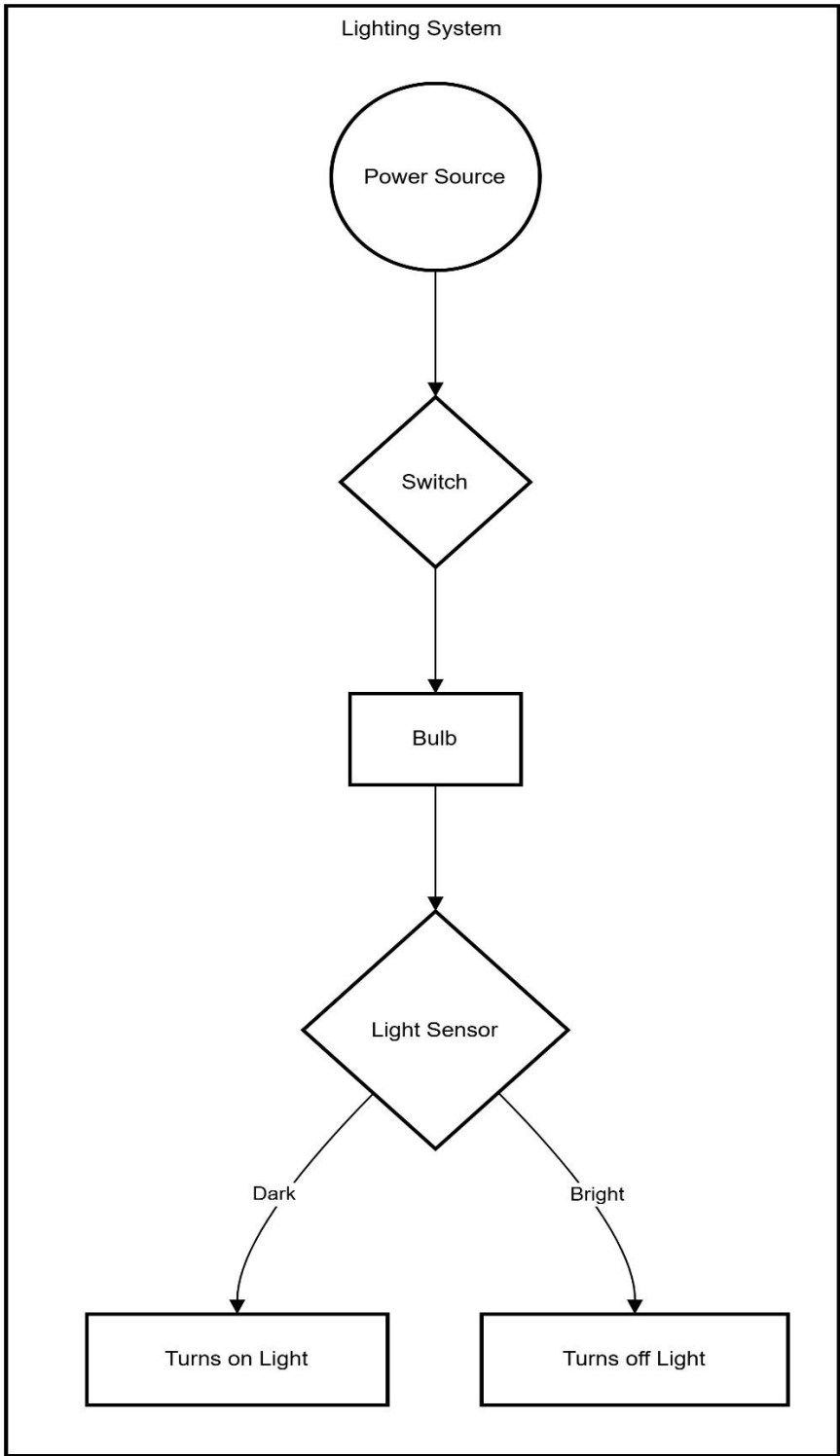
#### 3.1 EXISTING SYSTEM

The current lighting systems in most residential, commercial, and industrial settings rely on traditional methods of operation, such as manual switches, timers, or pre-set schedules. These systems are often inefficient, as they do not adapt to real-time conditions such as occupancy, natural light availability, or user preferences. Key components of the existing system include:

- a. **Manual Control:** Users manually turn lights on or off using switches, which can lead to lights being left on unnecessarily, resulting in energy waste.
- b. **Timer-Based Systems:** Some systems use timers to control lighting, but these are static and do not account for changes in occupancy or daylight availability.
- c. **Basic Sensors:** A few advanced systems incorporate motion sensors or light sensors, but these are often standalone and not integrated into a comprehensive smart lighting solution.
- d. **Energy-Efficient Lighting:** The adoption of LED lighting has improved energy efficiency, but without intelligent control, the full potential of energy savings is not realized.
- e. **Lack of Integration:** Existing systems are rarely integrated with other building management systems, such as HVAC or security, limiting their ability to contribute to overall energy efficiency.

While these systems provide basic functionality, they lack the intelligence and adaptability required to optimize energy consumption and enhance user comfort in real-time.

f. Existing System Software: While traditional systems may not have sophisticated software, there may be basic control mechanisms (e.g., timer-based code for simple systems). Any existing software here can be briefly referenced and noted as non-dynamic, which is a key area of improvement.



**Fig12. Flowchart of a Traditional lighting-system**

## 3.2 PROBLEMS OF THE EXISTING SYSTEM

The existing lighting systems face several challenges that hinder their efficiency and effectiveness:

- a. Energy Waste: Lights are often left on in unoccupied rooms or during daylight hours, leading to unnecessary energy consumption.
- b. Lack of Real-Time Adaptation: Systems cannot adjust lighting levels based on real-time factors such as occupancy or ambient light conditions.
- c. High Operational Costs: Inefficient lighting systems result in higher electricity bills and increased maintenance costs.
- d. Limited User Control: Users have limited control over lighting settings, making it difficult to personalize lighting for comfort or productivity.
- e. Poor Integration: The lack of integration with other smart systems (e.g., HVAC, security) prevents holistic energy management.
- f. Environmental Impact: Excessive energy consumption contributes to a larger carbon footprint, undermining sustainability efforts.
- g. Scalability Issues: Traditional systems are difficult to scale for larger installations, such as commercial buildings or campuses.
- h. User Inconvenience: Manual control and lack of automation lead to a suboptimal user experience.

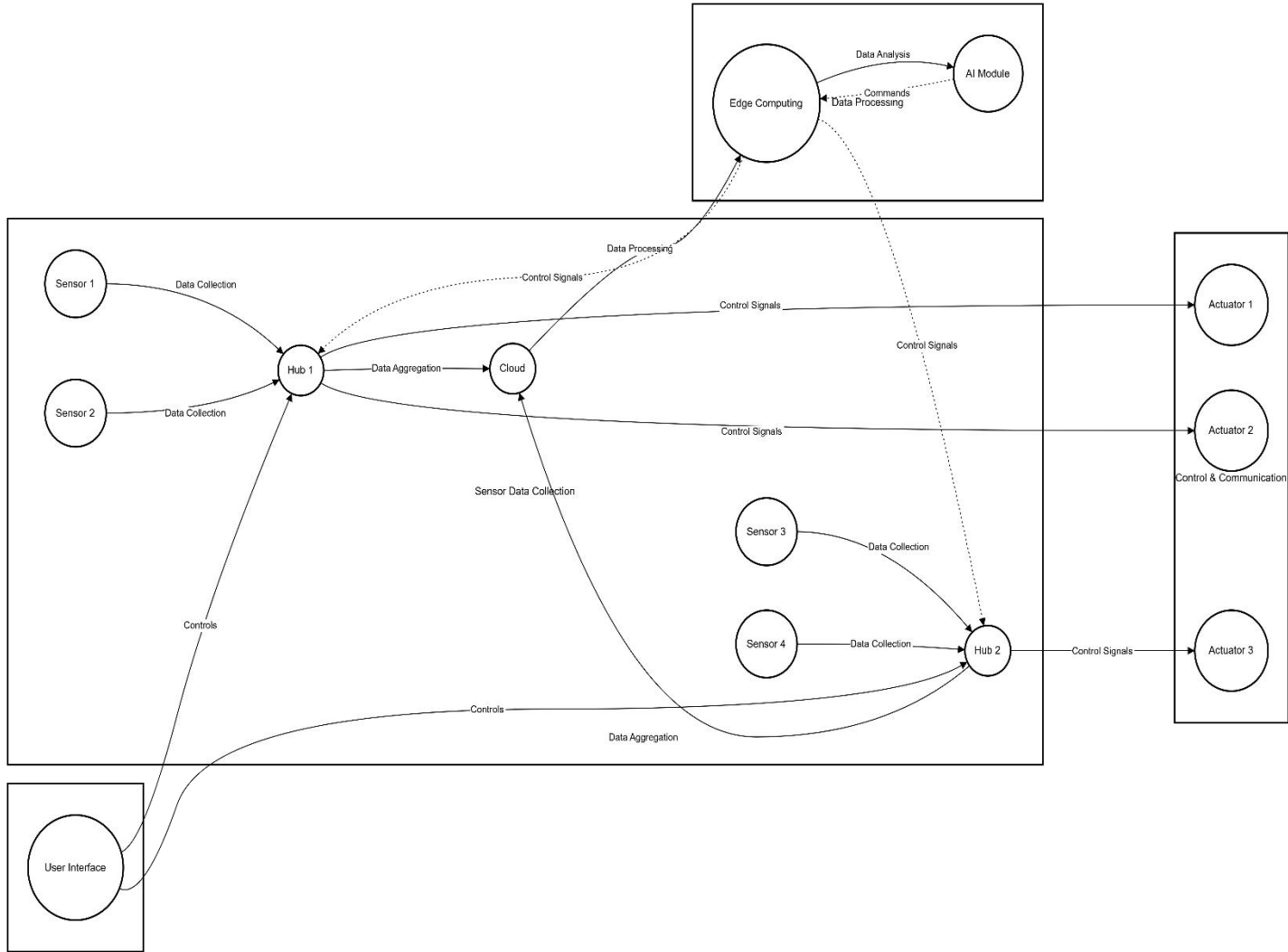
i. Lack of Dynamic Control: Traditional systems are typically not programmed to respond to real-time inputs from sensors or user preferences. The limitation in adaptability of existing code is an essential factor for improvement in your new system.

### **3.3 THE NEW SYSTEM**

The proposed Real-Time Energy-Efficient Smart Lighting System addresses the limitations of traditional systems by leveraging advanced technologies such as IoT, AI, and machine learning. The new system is designed to automatically adjust lighting based on real-time data, including occupancy, ambient light levels, and user preferences. Key features of the new system include:

- a. Real-Time Adaptation: The system dynamically adjusts lighting levels based on occupancy and ambient light conditions, ensuring optimal energy usage.
- b. Sensor Integration: Advanced sensors, such as motion sensors, light sensors, and occupancy sensors, are integrated to provide accurate real-time data.
- c. AI and Machine Learning: AI algorithms analyze data to predict user behavior and optimize lighting settings for energy efficiency and user comfort.
- d. User-Friendly Interface: A mobile or web-based interface allows users to control and monitor the system easily.
- e. Integration with Building Systems: The system can be integrated with other building automation systems (e.g., HVAC, security) for holistic energy management.
- f. Scalability: The system is designed to scale seamlessly for larger installations, such as commercial buildings or campuses.

g. Energy Savings: By optimizing lighting usage, the system significantly reduces energy consumption and operational costs.



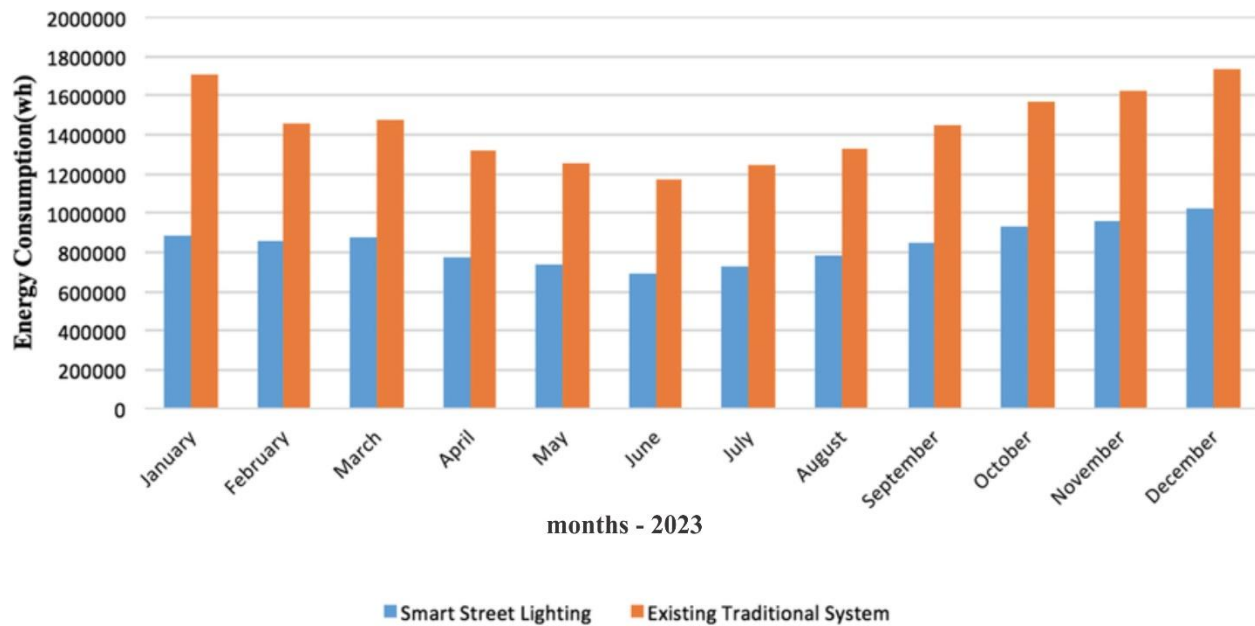
**Fig13. The-architecture-of-the-smart-lighting-system\**

### 3.4 BENEFITS OF THE NEW SYSTEM

The proposed system offers numerous advantages over traditional lighting systems:

a. Energy Efficiency: Real-time adjustments reduce energy waste, leading to significant cost savings.

- b. Enhanced User Comfort: Personalized lighting settings improve user comfort and productivity.
- c. Environmental Sustainability: Reduced energy consumption lowers the carbon footprint, contributing to environmental conservation.
- d. Cost Savings: Lower electricity bills and reduced maintenance costs result in long-term financial benefits.
- e. Scalability: The system can be easily scaled for larger installations, making it suitable for various applications.
- f. Integration Capabilities: Seamless integration with other smart systems enhances overall building efficiency.
- g. User Convenience: Automated control and a user-friendly interface improve the overall user experience.
- h. Data-Driven Insights: The system provides valuable data on energy usage and user behavior, enabling further optimization.



**Fig14.Comparison-of-monthly-energy-consumption-between-smart-street-lighting-and-existing**

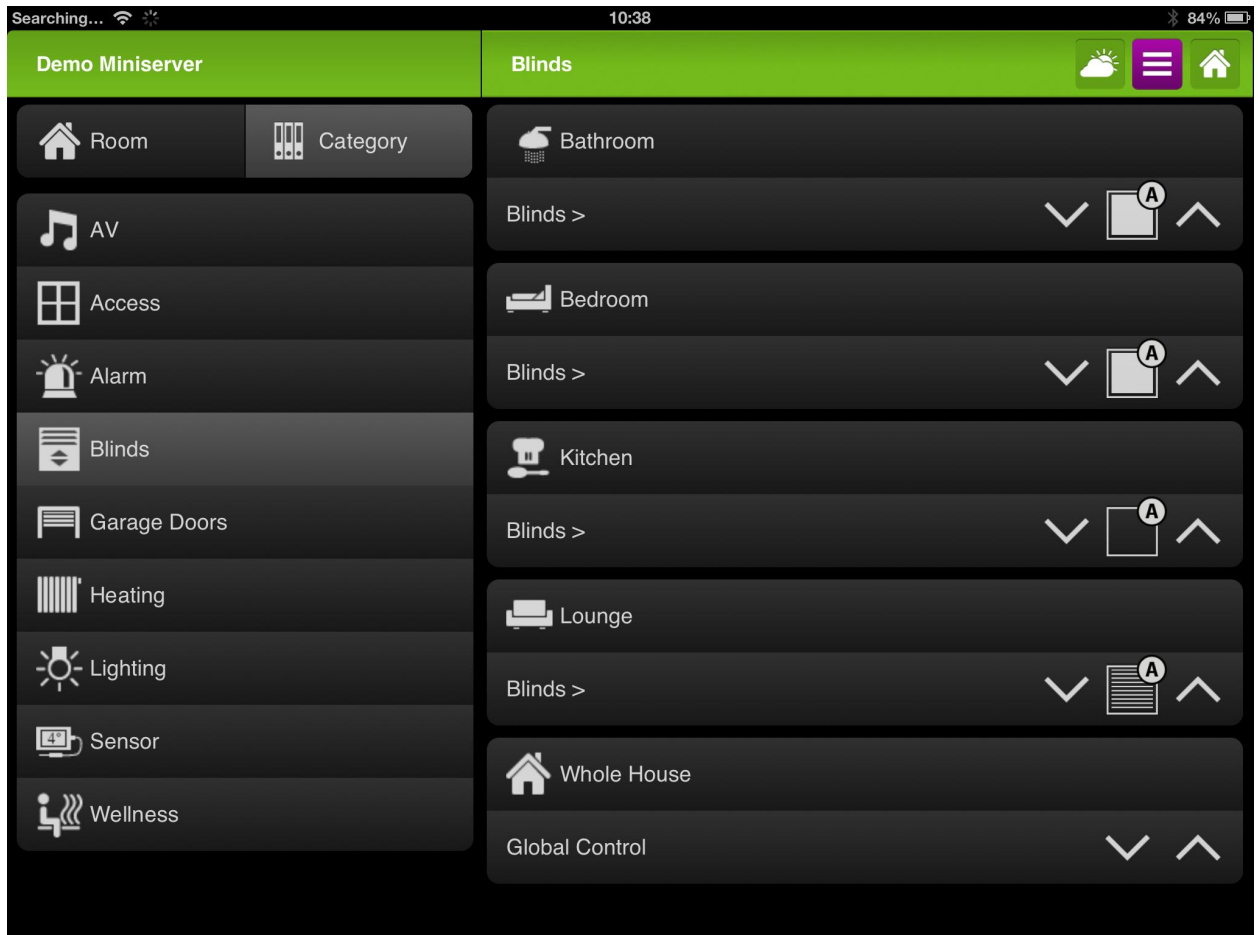
### 3.5 DESIGN OF THE PROPOSED SYSTEM

The proposed system is designed to be a comprehensive solution for real-time energy-efficient lighting. The design process involves the following key components:

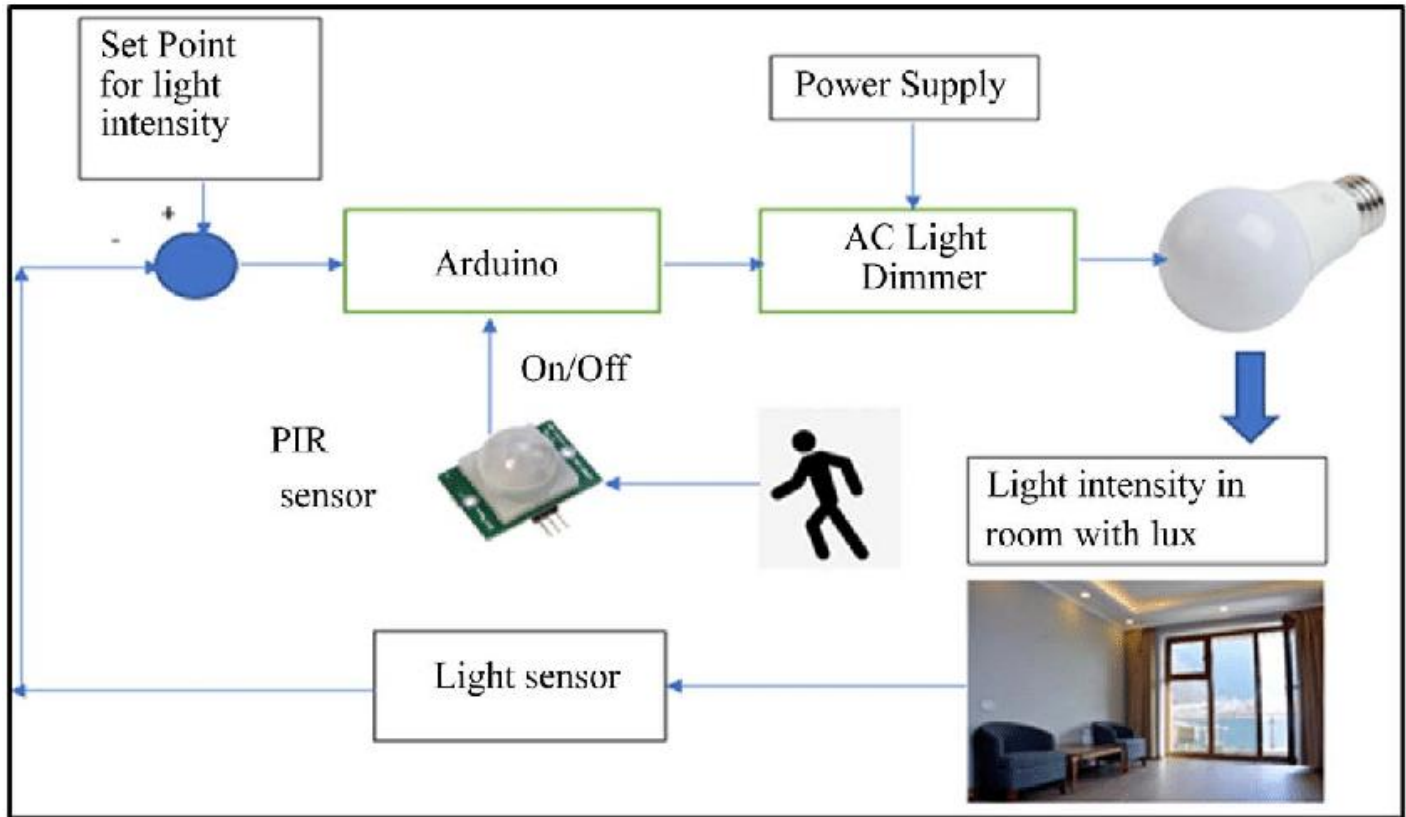
- a. System Architecture: The system consists of hardware (sensors, controllers, LED lights) and software (AI algorithms, user interface).
- b. Sensor Integration: Motion sensors, light sensors, and occupancy sensors are integrated to collect real-time data.
- c. AI and Machine Learning: AI algorithms analyze sensor data to predict user behavior and optimize lighting settings.
- d. User Interface: A mobile or web-based interface allows users to control and monitor the system.

e. Integration with Building Systems: The system is designed to integrate with other building automation systems for holistic energy management.

f. Scalability: The system is modular and can be scaled for larger installations.



**Fig15. Image of how the mobile app User interface looks like**



**Fig16. Block diagram of a smart lightening system**

### 3.6 DESIGN APPROACH

The design approach for the proposed system involves the following steps:

- a. Problem Definition: Clearly define the problem of energy inefficiency in traditional lighting systems and outline the goals of the new system.
- b. Data Collection: Gather data on occupancy patterns, ambient light levels, and energy consumption in the target environment.
- c. Data Preprocessing: Clean and preprocess the data to ensure it is suitable for analysis and algorithm training.

- d. Sensor Selection and Integration: Select appropriate sensors (e.g., motion sensors, light sensors) and integrate them into the system.
- e. Algorithm Development: Develop AI and machine learning algorithms to optimize lighting based on real-time data.
- f. User Interface Design: Design an intuitive and user-friendly interface for system control and monitoring.
- g. Testing and Evaluation: Test the system in a real-world environment to evaluate its performance and effectiveness.
- h. Deployment: Deploy the system in the target environment and ensure seamless integration with existing infrastructure.
- i. Ethical Considerations: Implement safeguards to address privacy concerns and ensure ethical use of the system.
- j. Continuous Improvement: Monitor system performance and gather user feedback for ongoing improvements and updates.

### **3.7 DETAILED FUNCTIONAL REQUIREMENTS**

To ensure the effectiveness of the proposed smart lighting system, the following detailed functional requirements must be met:

**Real-Time Lighting Adjustment:** The system must automatically adjust lighting levels based on the detected occupancy and the amount of available natural light. For example, if the room is empty, lights should turn off; if ambient light is high, the system should dim the lights.

User Control Interface: The system must allow users to manually override automatic settings via a mobile app or web interface. Users must be able to adjust the brightness, set schedules, and view real-time energy consumption.

Energy Consumption Monitoring: The system should provide real-time data on energy usage, presenting it in an easy-to-understand format (e.g., graphs or charts) for users to monitor and control energy consumption effectively.

Scheduling and Customization: Users should be able to set lighting schedules (e.g., lights automatically turn on/off at specified times) and customize settings based on personal preferences or activity types (e.g., reading, working, entertainment).

Safety and Security Features: The system should notify users of any unusual activities such as lights being left on when the building is unoccupied, or motion detected in areas where no one is expected.

### **3.8 NON-FUNCTIONAL REQUIREMENTS**

In addition to the functional specifications, non-functional requirements for the system include:

Performance Requirements:

Speedy response: The system must provide real-time responses, with lighting adjustments occurring within 1-2 seconds after a change in occupancy or ambient light conditions.

Reliability and Availability: The system should have 99.9% uptime. Failures should be rare, and there should be a clear recovery mechanism in place if a failure occurs.

**Security:** The system must include secure data transmission using encryption (e.g., SSL/TLS) for all communication between devices. Authentication mechanisms should be in place to ensure only authorized users can control or configure the system.

**Scalability:** The system must be designed to scale from a single home to large-scale commercial applications, supporting hundreds or thousands of devices without performance degradation.

### **3.9 SYSTEM WORKFLOW AND INTERACTION DIAGRAMS**

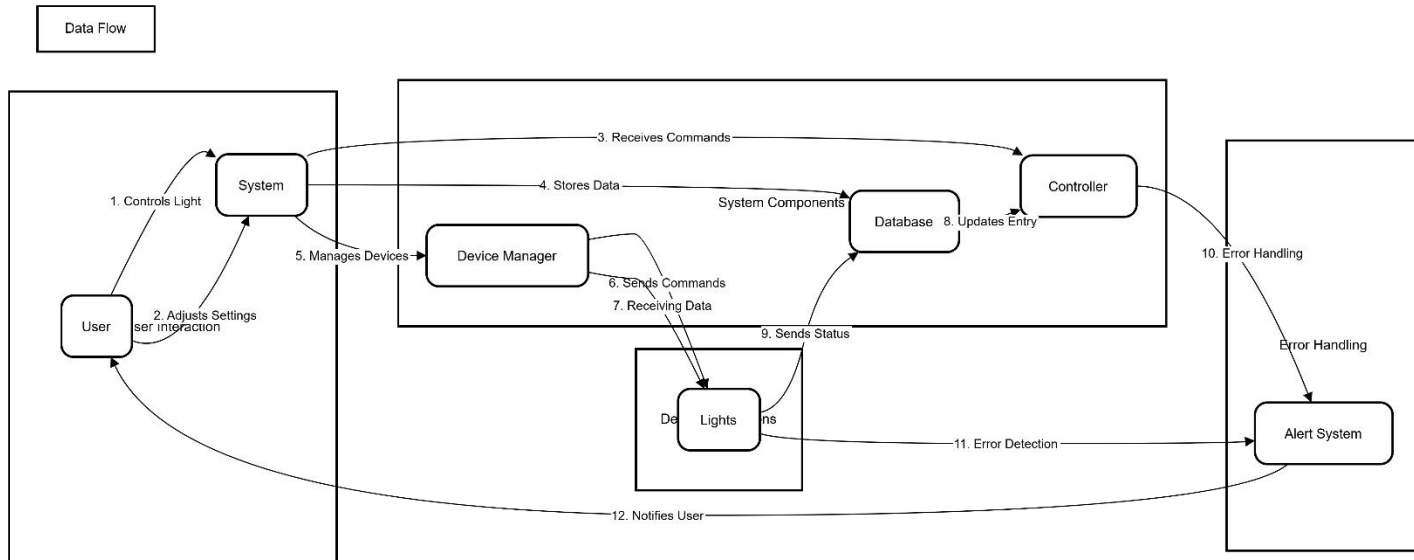
The system workflow defines how users interact with the system and how data flows within the system. Below are the key components of the interaction:

**Sensor Detection:** Sensors continuously monitor occupancy and ambient light levels. When a change is detected, the data is sent to the central controller.

**Data Processing:** The central controller (or cloud-based system) analyzes the sensor data, using AI algorithms to determine the optimal lighting adjustments based on pre-set rules or real-time environmental data.

**User Interaction:** Users can access and modify settings via the mobile or web interface, providing them with manual control over the system.

**Feedback Loop:** Once the system makes adjustments, it continuously monitors the effect and may make further refinements as necessary, optimizing both energy efficiency and user comfort.



**Fig17. System Interaction Diagram**

### 3.10 TECHNOLOGY STACK AND INFRASTRUCTURE

The proposed system is built on a modern technology stack to ensure seamless operation, scalability, and performance:

Hardware:

Sensors: Motion sensors, light sensors, and occupancy sensors (e.g., PIR sensors).

LED Lights: Energy-efficient LED lights with dimming capabilities.

Microcontrollers: Used to interface between sensors and the system for real-time processing.

Connectivity: Wi-Fi or Zigbee for device communication.

Software:

Cloud Infrastructure: AWS or Google Cloud for data storage and machine learning models.

AI/ML Frameworks: TensorFlow, Keras for machine learning algorithms to predict user behavior and optimize lighting.

Mobile/Web Interface: Developed using React Native for mobile and ReactJS for web, providing users with easy-to-use control panels.

Database:

SQL or NoSQL Database: To store historical data on energy consumption, user preferences, and sensor data (e.g., MongoDB, Firebase).

### **3.11 SECURITY AND PRIVACY CONSIDERATIONS**

As the system collects sensitive data such as occupancy patterns and light usage, it must adhere to high security standards:

**Data Encryption:** All data in transit between sensors, controllers, and user devices must be encrypted using industry-standard encryption protocols (e.g., TLS, AES).

**Access Control:** Role-based access control (RBAC) will be implemented to ensure that only authorized users can access or modify system settings. Multi-factor authentication (MFA) will be used for user login.

**Data Storage:** Any data collected by the system (such as occupancy data) should be stored in an anonymized and encrypted format to preserve user privacy.

**Security Audits:** Regular audits should be conducted to ensure compliance with security best practices and to identify potential vulnerabilities.

### **3.12 DATA ANALYTICS AND REPORTING FEATURES**

The system will include a robust data analytics module that provides users and building administrators with useful insights:

**Energy Consumption Reports:** Users will receive monthly reports showing the energy consumption of lights, highlighting periods of excessive usage. These reports will be accessible via the mobile/web interface.

**Predictive Analytics:** The system will use machine learning algorithms to predict future energy consumption patterns, enabling users to make proactive decisions about energy usage.

**Customizable Dashboards:** Users will be able to create personalized dashboards that track specific metrics, such as energy savings or lights' operational status.

### **3.13 USER FEEDBACK AND ADAPTATION**

The system will be designed to adapt based on user preferences and behaviors:

**Customizable Preferences:** Users can define light settings for specific activities (e.g., reading, working, entertainment), and the system will automatically adjust the lighting when it detects that activity based on sensors.

**User Feedback Mechanism:** A feedback system will allow users to rate their experience, enabling continuous improvement of the lighting system. Feedback can also include suggestions for new features or changes in behavior.

### **3.14 TESTING AND VALIDATION METHODOLOGY**

The testing phase will involve several stages to ensure the system performs as expected:

**Unit Testing:** Each component (sensor, controller, mobile app) will be tested individually to ensure it functions correctly.

**Integration Testing:** The interaction between sensors, controllers, and the user interface will be tested to ensure data is properly exchanged and processed.

**User Acceptance Testing (UAT):** A group of end-users will interact with the system in a controlled environment, providing feedback on usability and functionality.

**Load Testing:** The system will undergo stress tests to ensure that it performs well even under heavy loads, particularly in large-scale commercial applications.

## CHAPTER FOUR

### SYSTEM IMPLEMENTATION AND DESIGN

#### 4.1 SYSTEM IMPLEMENTATION

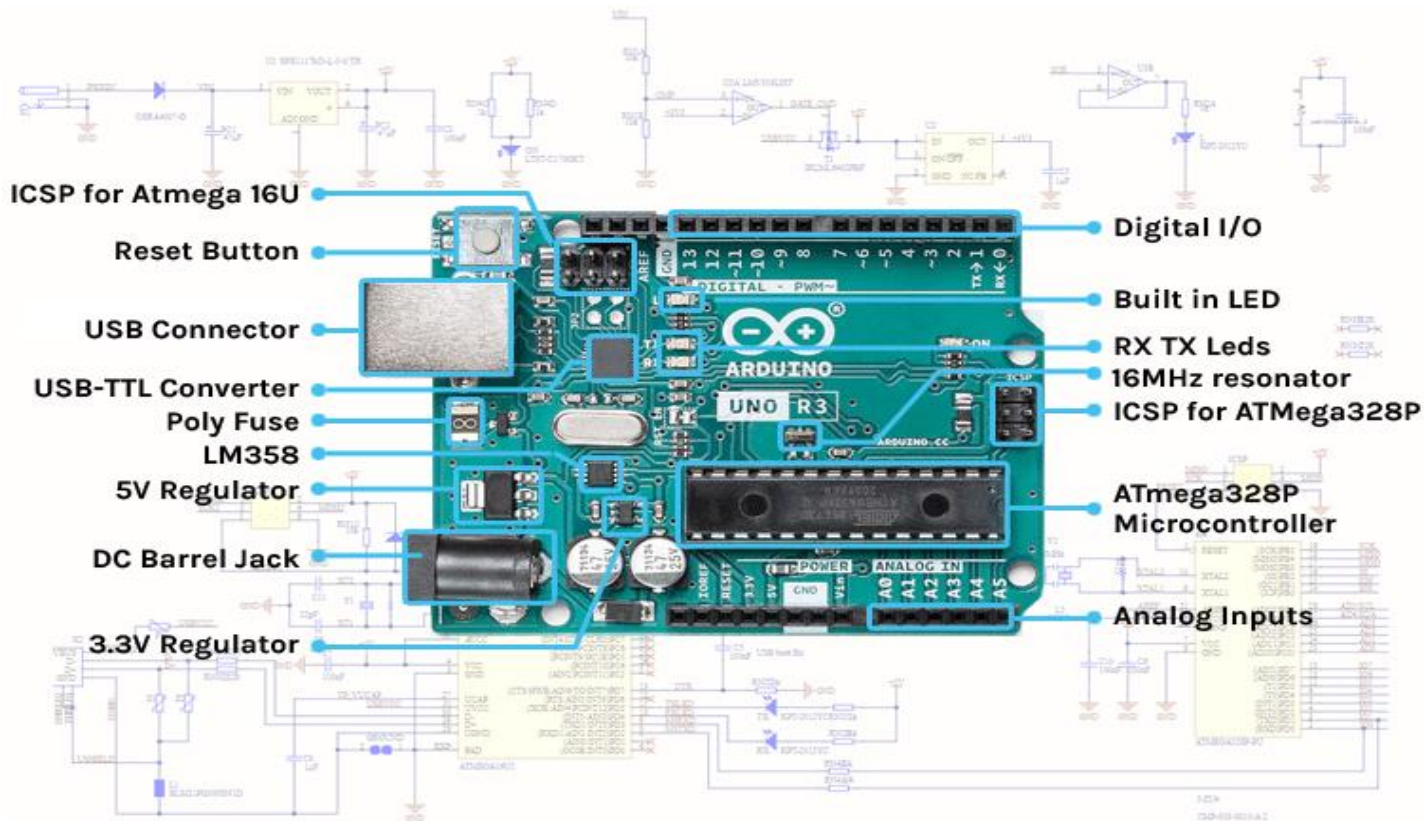
The implementation of the **Real-Time Energy-Efficient Smart Lighting System** involves the integration of hardware and software components to create a functional and efficient system. The implementation process is divided into the following stages:

##### 4.1.1 Hardware Components

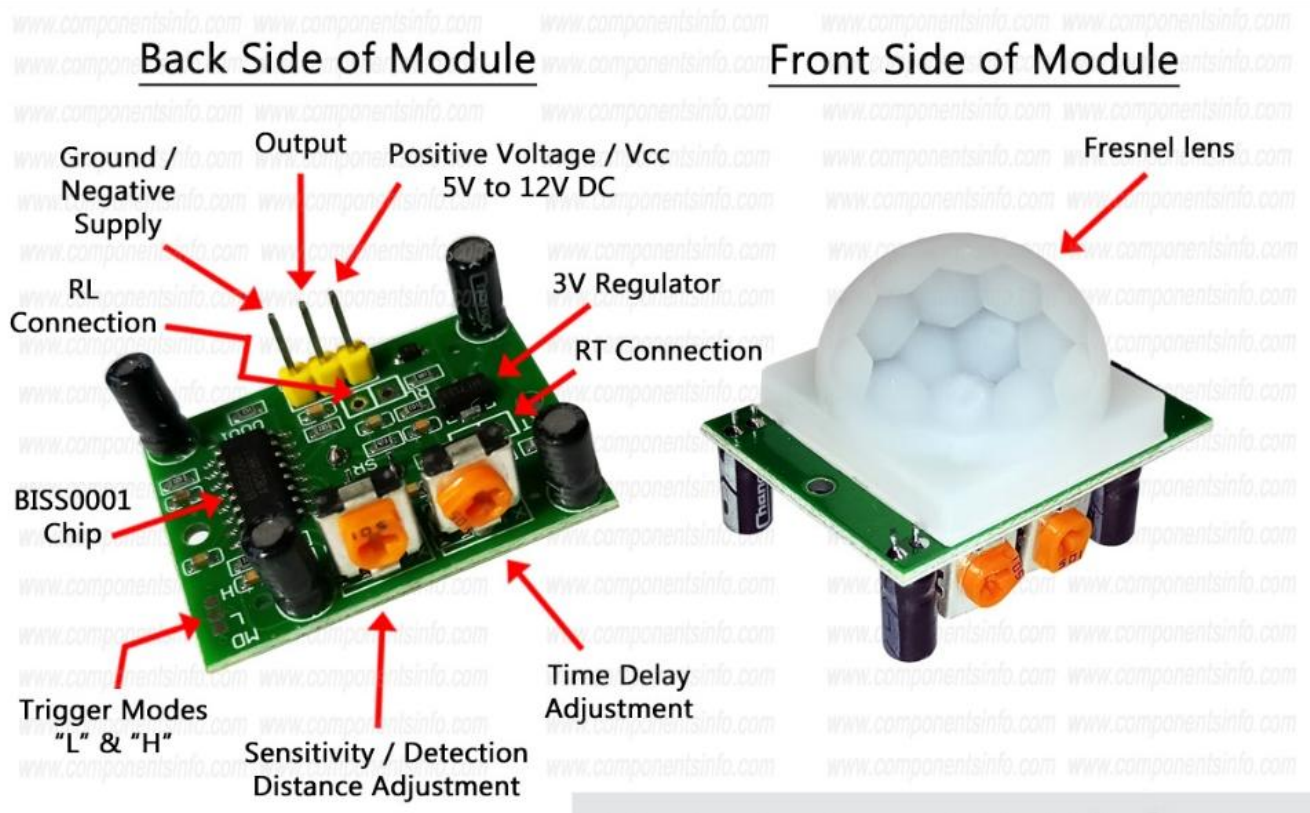
The hardware components form the physical foundation of the system and include:

- **Sensors:**
  - **Motion Sensors:** Detect occupancy in a room or area.
  - **Light Sensors:** Measure ambient light levels to determine the need for artificial lighting.
  - **Occupancy Sensors:** Provide data on the presence and movement of people in a space.
- **Controllers:**
  - **Microcontrollers (e.g., Arduino, Raspberry Pi):** Process sensor data and control lighting fixtures.
  - **Relay Modules:** Used to switch lights on or off based on controller commands.
- **Lighting Fixtures:**
  - **Energy-efficient LED Lights:** The primary lighting source.

- **Dimmable LEDs:** Allow for adjustable brightness levels based on real-time conditions.
- **Communication Modules:**
  - **Wi-Fi or Zigbee Modules:** Enable wireless communication between sensors, controllers, and the central system.
  - **IoT Gateways:** Facilitate data exchange between the system and cloud-based platforms.
- **Power Supply:**
  - **Solar Panels:** Can be integrated to provide renewable energy for the system, especially in outdoor or remote application.



**Fig18. Image of Arduino micro controller**



**Fig19. Image of motion sensor**

**4.1.2 Software Components:** The software components enable intelligent control and optimization of the system:

- **Data Collection and Processing:**
  - Sensor data (e.g., occupancy, ambient light) is collected and processed in real-time.
  - Data is stored in a local or cloud-based database for analysis.
- **AI and Machine Learning Algorithms:**
  - **Algorithms** analyze historical and real-time data to predict occupancy patterns and optimize lighting settings.

- Machine learning models dynamically adjust lighting based on user behavior and environmental conditions.
- **User Interface:**
  - A mobile or web-based application allows users to control and monitor the system.
  - Features include manual override, scheduling, and real-time energy usage tracking.
- **Integration with Building Systems:**
  - The system integrates with other building automation systems (e.g., HVAC, security) for holistic energy management.
  - APIs enable seamless communication between different systems.

## 4.2 SYSTEM DESIGN

The design of the **Real-Time Energy-Efficient Smart Lighting System** is based on a modular and scalable architecture. The system is divided into the following layers:

### 4.2.1 System Architecture

The system architecture consists of three main layers:

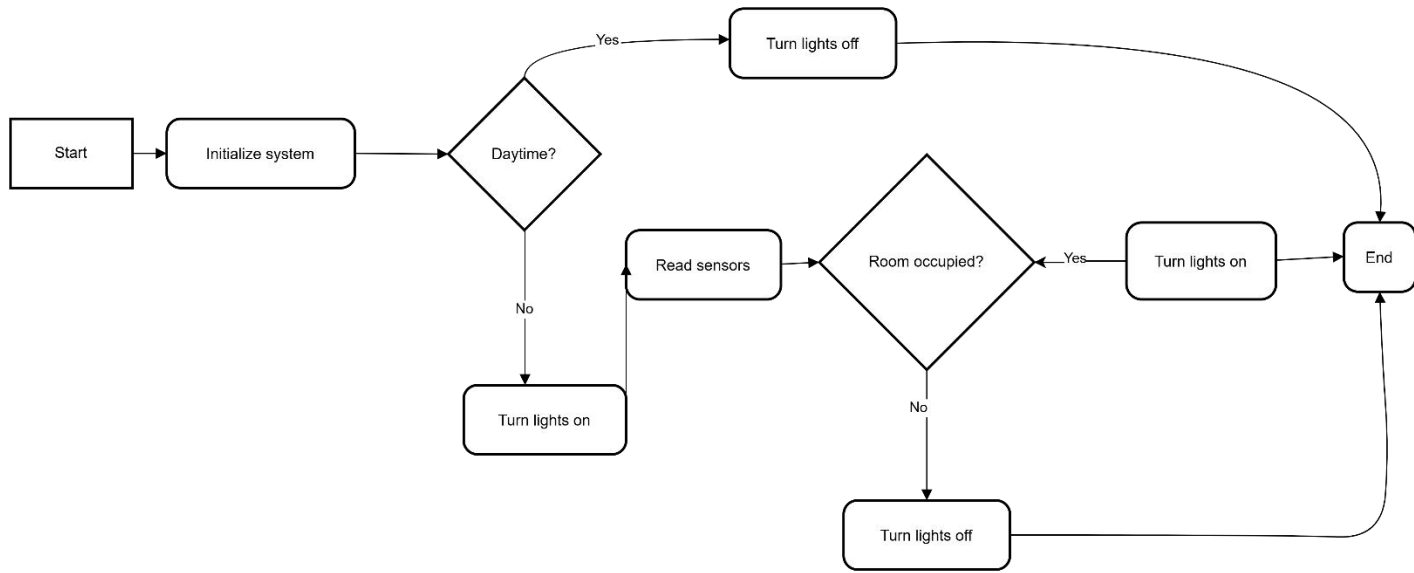
- **Perception Layer:**
  - Includes sensors and actuators that collect data and control lighting fixtures.
  - Sensors detect occupancy, ambient light, and other environmental factors.
- **Network Layer:**
  - Facilitates communication between the perception layer and the application layer.
  - Uses wireless communication protocols (e.g., Wi-Fi, Zigbee) for data transmission.

- **Application Layer:**
  - Processes data and implements AI algorithms for real-time optimization.
  - Provides a user interface for system control and monitoring.

## 4.2.2 Workflow of the System

The workflow of the system is as follows:

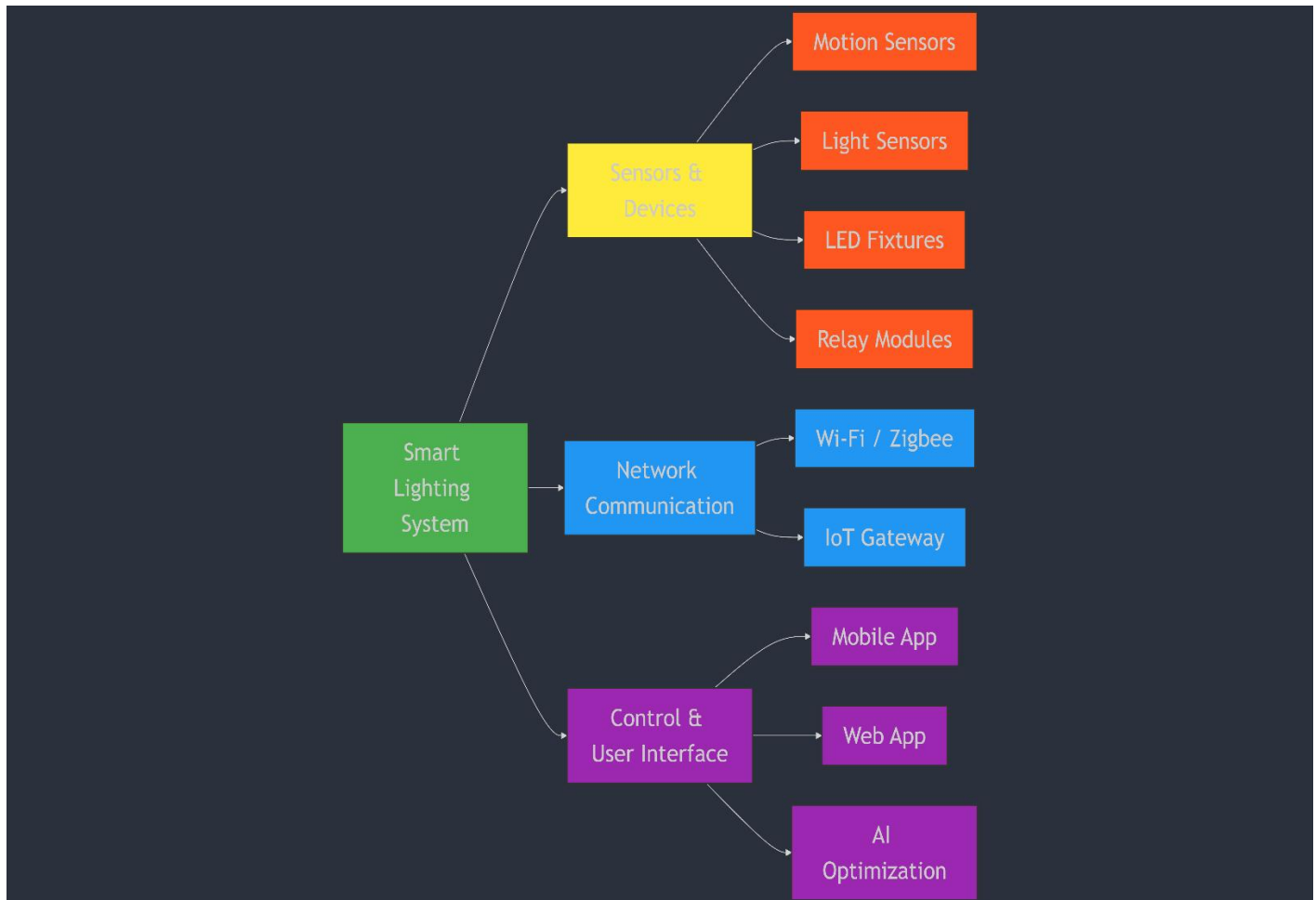
1. **Data Collection:** Sensors collect real-time data on occupancy and ambient light levels.
2. **Data Transmission:** Data is transmitted to the central controller via wireless communication modules.
3. **Data Processing:** The controller processes the data and applies AI algorithms to determine optimal lighting settings.
4. **Lighting Control:** The controller sends commands to the lighting fixtures to adjust brightness or turn lights on/off.
5. **User Interaction:** Users can monitor and control the system through a mobile or web-based interface.
6. **Integration:** The system communicates with other building automation systems for holistic energy management.



**Fig20. System workflow for smart lightening**

### 4.2.3 System Design Diagram

Below is a high-level diagram illustrating the system design:



**Fig 21. System design**

## 4.3 IMPLEMENTATION STEPS

The implementation of the system involves the following steps:

### 1. **Hardware Setup:**

- Install sensors (motion, light, occupancy) in the target environment.
- Connect sensors to microcontrollers (e.g., Arduino, Raspberry Pi).
- Set up LED lighting fixtures and connect them to relay modules.

### 2. **Software Development:**

- Develop firmware for microcontrollers to process sensor data and control lighting.
- Implement AI and machine learning algorithms for real-time optimization.
- Create a user interface (mobile or web-based) for system control and monitoring.

### 3. **System Integration:**

- Integrate sensors, controllers, and lighting fixtures into a cohesive system.
- Enable communication between the system and cloud-based platforms for data storage and analysis.
- Integrate the system with other building automation systems (e.g., HVAC, security).

### 4. **Testing and Calibration:**

- Test the system in a controlled environment to ensure accurate sensor readings and proper lighting control.
- Calibrate sensors and algorithms to optimize system performance.

### 5. **Deployment:**

- Deploy the system in the target environment (e.g., university building, office space).
- Monitor system performance and gather user feedback for further improvements.



**Fig 22. Hardware setup**

## **4.4 SOFTWARE AND TECHNOLOGY CHOICES**

### **4.4.1 Programming Languages and Frameworks**

- **Front-End:**
  - **React.js (JavaScript):** For building a dynamic and responsive user interface for controlling and monitoring the system.

- **React Native** (if applicable): For mobile app development, allowing users to control lighting on the go.
  
- **Back-End:**
  - **Node.js (Express.js)**: For the server-side application, managing real-time communication between the user interface and the microcontrollers.
  - **Socket.IO** (optional): For handling real-time communication between the server and the user interface.
  
- **Integration with IoT Devices:**
  - **MQTT** or **Johnny-Five** (for Arduino/Raspberry Pi integration): For communication between sensors and controllers.
  
- **Database:**
  - **MongoDB** or **PostgreSQL**: To store user preferences, lighting history, and energy consumption data.

#### 4.4.2 Deployment and Hosting

- **Front-End Hosting:**
  - Deploy the React.js app using platforms like **Netlify** or **Vercel** for fast and efficient hosting.
  
- **Back-End Hosting:**
  - Host the server-side app on platforms like **Heroku**, **AWS**, or **Google Cloud Platform** for scalability and reliability.

## 4.5 SYSTEM EVALUATION

The system is evaluated based on the following metrics:

- **Energy Efficiency:** Measure the reduction in energy consumption compared to traditional lighting systems.
- **User Comfort:** Assess user satisfaction with lighting quality and system usability.
- **System Responsiveness:** Evaluate the system's ability to adapt to real-time changes in occupancy and ambient light.
- **Cost Savings:** Analyze the financial benefits of reduced energy consumption and maintenance costs.
- **Environmental Impact:** Quantify the reduction in carbon footprint achieved by the system.

## CODE IMPLEMENTATION

### LDR-based Light Control

```
// Define pins for components
const int ldrPin = A0; // LDR connected to analog pin A0
const int ledPin = 9; // LED connected to digital pin 9 (PWM pin)

int ldrValue = 0; // Variable to store LDR sensor value
int threshold = 500; // LDR value threshold for controlling LED brightness

void setup() {
  // Initialize serial communication for debugging
  Serial.begin(9600);

  // Initialize the LED pin as output
  pinMode(ledPin, OUTPUT);

  // Initialize the LDR pin as input
  pinMode(ldrPin, INPUT);
}

void loop() {
  // Read the value from LDR sensor (light level)
  ldrValue = analogRead(ldrPin);

  // Print the sensor value to the serial monitor
  Serial.print("LDR Value: ");
  Serial.println(ldrValue);
}
```

```

// If the light is low (LDR value is below threshold), turn on LED or increase brightness
if (ldrValue < threshold) {
  // Map the LDR value to PWM range (0-255) for LED dimming
  int brightness = map(ldrValue, 0, threshold, 255, 0);
  analogWrite(ledPin, brightness);
} else {
  // If the light is sufficient, turn off the LED
  analogWrite(ledPin, 0);
}

// Delay to avoid excessive reading frequency
delay(200);
}

```

## Temperature-based LED Control

```

#include <DHT.h>

// Define DHT sensor
#define DHTPIN 2      // Pin where the DHT sensor is connected
#define DHTTYPE DHT11 // Define the sensor type (DHT11 or DHT22)

DHT dht(DHTPIN, DHTTYPE); // Initialize DHT sensor

const int ledPin = 9;      // LED pin (PWM control)

void setup() {
  Serial.begin(9600);
  pinMode(ledPin, OUTPUT);

  dht.begin(); // Initialize DHT sensor
}

void loop() {
  // Read temperature
  float temperature = dht.readTemperature();
}

```

```
// Check if the reading failed
if (isnan(temperature)) {
  Serial.println("Failed to read from DHT sensor!");
  return;
}

Serial.print("Temperature: ");
Serial.println(temperature);

// Control LED brightness based on temperature
int brightness = map(temperature, 20, 30, 0, 255);

// Apply brightness based on temperature
analogWrite(ledPin, brightness);

delay(2000); // Delay for 2 seconds before next reading
}
```

## Decision Trees for Brightness Control

```
from sklearn.tree import DecisionTreeRegressor
import numpy as np
import pandas as pd

# Sample data
# Each row represents [ambient light, temperature, humidity, occupancy] and target is the bright
data = {
    'ambient_light': [100, 200, 50, 500, 150, 10],
    'temperature': [22, 25, 21, 23, 24, 30],
    'humidity': [60, 55, 70, 65, 50, 40],
    'occupancy': [1, 0, 1, 1, 0, 1], # 1 for occupied, 0 for unoccupied
    'brightness': [200, 50, 255, 100, 255, 20] # Target brightness level
}

df = pd.DataFrame(data)

# Define inputs and output
X = df[['ambient_light', 'temperature', 'humidity', 'occupancy']]
y = df['brightness']

# Train a decision tree model
model = DecisionTreeRegressor()
model.fit(X, y)

# Sample prediction (new sensor data)
new_data = np.array([[150, 22, 55, 1]]) # ambient light, temperature, humidity, occupancy
predicted_brightness = model.predict(new_data)

print(f"Predicted Brightness: {predicted_brightness[0]}")
```

## Real-time Control with Arduino

```
#include <Servo.h>

const int ldrPin = A0; // LDR sensor pin
const int pirPin = 2; // PIR sensor pin
const int ledPin = 9; // LED pin (PWM)

int ldrValue = 0;
int occupancy = 0; // 0 = no one, 1 = occupied

Servo led; // PWM control of LED brightness

void setup() {
  Serial.begin(9600);
  pinMode(ldrPin, INPUT);
  pinMode(pirPin, INPUT);
  led.attach(ledPin); // Attach LED for PWM control
}

void loop() {
  ldrValue = analogRead(ldrPin);
  occupancy = digitalRead(pirPin);

  // Example: Use the trained model to predict brightness (for simplicity, a linear mapping is
  int brightness = map(ldrValue, 0, 1023, 255, 0); // Convert LDR value to brightness level

  if (occupancy == 1) {
    led.write(brightness); // Set brightness when room is occupied
  } else {
    led.write(0); // Turn off LED when room is unoccupied
  }

  delay(500);
}
```

index.html

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>Smart Lighting Control System</title>
    <link rel="stylesheet" href="styles.css">
  </head>
  <body>
    <div class="container">
      <h1>Smart Lighting System</h1>

      <!-- Display Current Status -->
      <div class="status">
        <p><strong>Light Status:</strong> <span id="light-status">OFF</span></p>
        <p><strong>Brightness:</strong> <span id="brightness-level">0%</span></p>
        <p><strong>Energy Usage:</strong> <span id="energy-usage">0 kWh</span></p>
      </div>

      <!-- Lighting Controls -->
      <div class="controls">
        <button id="toggle-light" onclick="toggleLight()">Toggle Light</button>
        <input type="range" id="brightness-slider" min="0" max="100" value="0" onchange="
        <label for="brightness-slider">Adjust Brightness</label>
      </div>

      <!-- Energy Monitoring -->
      <div class="energy-monitor">
        <button onclick="optimizeEnergy()">Optimize Energy</button>
      </div>
    </div>

    <script src="script.js"></script>
  </body>
</html>
```

styles.css

```
body {
  font-family: Arial, sans-serif;
  margin: 0;
  padding: 0;
  background-color: #f4f4f9;
  display: flex;
  justify-content: center;
  align-items: center;
  height: 100vh;
}

.container {
  text-align: center;
  background-color: white;
  padding: 30px;
  box-shadow: 0 4px 8px rgba(0, 0, 0, 0.1);
  border-radius: 5px;
}

h1 {
  color: #333;
}

.status, .controls, .energy-monitor {
  margin: 20px 0;
}

button {
  padding: 10px 20px;
  background-color: #4CAF50;
  border: none;
  color: white;
  font-size: 16px;
  cursor: pointer;
  border-radius: 5px;
}

button:hover {
  background-color: #45a049;
}

input[type="range"] {
  width: 80%;
}
```

script.js

```
// Function to toggle the light on/off
function toggleLight() {
  const currentState = document.getElementById("light-status").innerText;
  const newStatus = currentState === "OFF" ? "ON" : "OFF";
  document.getElementById("light-status").innerText = newStatus;

  // Send the command to the backend to toggle light
  fetch("/api/toggle-light", {
    method: "POST"
  })
  .then(response => response.json())
  .then(data => {
    console.log('Light toggled:', data);
  });
}

// Function to adjust the brightness
function adjustBrightness() {
  const brightness = document.getElementById("brightness-slider").value;
  document.getElementById("brightness-level").innerText = `${brightness}%`;

  // Send the brightness level to the backend
  fetch("/api/set-brightness", {
    method: "POST",
    headers: {
      'Content-Type': 'application/json'
    },
    body: JSON.stringify({ brightness: brightness })
  })
  .then(response => response.json())
  .then(data => {
    console.log('Brightness adjusted:', data);
  });
}

// Function to optimize energy usage
function optimizeEnergy() {
  // Send a request to the backend to optimize energy consumption
  fetch("/api/optimize-energy", {
    method: "POST"
  })
  .then(response => response.json())
  .then(data => {
    alert('Energy optimized!');
  });
}
```

server.js

```
const express = require('express');
const bodyParser = require('body-parser');
const app = express();
const port = 3000;

// Hook variables for lighting control
let lightStatus = "OFF";
let brightness = 0;
let energyUsage = 0;

// Middleware
app.use(bodyParser.json());
app.use(express.static('public')); // Serve static files like index.html, styles.css, script.

// Endpoint to toggle the light on/off
app.post('/api/toggle-light', (req, res) => {
  lightStatus = lightStatus === "OFF" ? "ON" : "OFF";
  energyUsage = lightStatus === "ON" ? 0.1 : 0; // Example energy usage (0.1 kWh when ON)
  res.json({ status: lightStatus, energyUsage: energyUsage });
});

// Endpoint to set brightness
app.post('/api/set-brightness', (req, res) => {
  const { brightness: newBrightness } = req.body;
  brightness = newBrightness;
  energyUsage = lightStatus === "ON" ? (newBrightness / 100) * 0.1 : 0; // Energy consumption
  res.json({ brightness: brightness, energyUsage: energyUsage });
});

// Endpoint to optimize energy usage
app.post('/api/optimize-energy', (req, res) => {
  if (lightStatus === "ON" && brightness > 50) {
    brightness = 50; // Reduce brightness to 50% for energy efficiency
    energyUsage = 0.05; // Update energy usage
  }
  res.json({ status: "optimized", brightness: brightness, energyUsage: energyUsage });
});

// Start server
app.listen(port, () => {
  console.log(`Server running at http://localhost:${port}`);
});
```

**Testing:** Run the server:

```
node server.js
```

## CHAPTER FIVE

### SUMMARY AND CONCLUSION

#### 5.1 SUMMARY

A real-time energy-efficient smart lighting system is an innovative solution that leverages modern technology to enhance energy conservation while providing effective lighting in various environments. The system utilizes sensors, artificial intelligence, and smart controls to adjust lighting based on occupancy, time of day, and ambient light conditions. At the University of Benin, this system can be integrated into classrooms, lecture halls, libraries, and other public spaces, ensuring optimal lighting while minimizing energy consumption.

This technology can benefit various departments, from enhancing the student learning experience with appropriate lighting conditions to supporting research environments where controlled lighting plays a crucial role. For example, in science and design laboratories, the smart system can maintain consistent lighting levels conducive to study or creative work. The system's energy-efficient nature aligns with sustainability goals, reducing electricity costs and minimizing the university's carbon footprint.

Furthermore, the integration of such a system within campus infrastructure can streamline building management, allowing for remote monitoring and control, which is vital for maintaining efficiency in large academic settings. The real-time responsiveness of the lighting system ensures comfort, convenience, and cost-effectiveness, fostering a better atmosphere for both students and faculty.

## **5.2 CONCLUSION**

In conclusion, the adoption of a real-time energy-efficient smart lighting system at the University of Benin presents significant advantages in promoting sustainable practices, optimizing lighting conditions, and reducing operational costs. By employing intelligent controls, sensors, and real-time data processing, the system ensures energy is utilized efficiently while maintaining a comfortable and conducive environment for teaching, learning, and research. The potential for energy savings, coupled with improved user experience, highlights the value of such a system in modern educational institutions.

As the world continues to focus on sustainability and environmental responsibility, the implementation of such smart technologies positions the University of Benin as a forward-thinking institution, ready to meet the challenges of the future. With the continuous advancement of smart technologies, this system could play a key role in reducing the university's environmental impact, contributing to a more sustainable campus.

## **5.3 RECOMMENDATIONS**

I recommend that the University of Benin move forward with the swift implementation of a real-time energy-efficient smart lighting system. This system can offer considerable energy savings, which would lead to reduced operational costs for the university while promoting a green, sustainable campus. The integration of this technology into university infrastructure can improve lighting conditions in classrooms, libraries, corridors, and outdoor spaces, creating a better overall experience for both students and faculty.

Additionally, regular monitoring of energy usage and system performance will ensure that the lighting system continues to operate efficiently. Providing training for the staff responsible for maintaining the system is essential to its successful implementation. Collaborations between the university's engineering, IT, and facilities management departments can facilitate a smooth rollout and integration.

The system should be scalable, allowing future upgrades to accommodate the growing needs of the campus. Further research into additional energy-efficient solutions could complement this initiative, creating a comprehensive approach to energy management at the university.

Lastly, it is important to ensure that the technology meets necessary security standards, particularly when dealing with data generated by sensors and smart controls. Protection of user privacy and system security should be prioritized to prevent unauthorized access or potential vulnerabilities.

By adopting this system, the University of Benin will enhance its sustainability efforts and become a leader in implementing smart technology in education, serving as a model for other institutions.

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