Design and Analysis of Smart Lighting System for Room Environments Using Simulation Supporting Diverse Light Bulbs

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***Abstract*—Recently, the demand for intelligent, energy-efficient lighting systems has increased due to rising environmental concerns and increasing electricity consumption in smart room environment buildings. Conventional lighting systems often operate inefficiently, using outdated bulb technologies and lacking automation, which results in substantial energy waste, especially in rooms with variable occupancy. Lighting significantly contributes to energy consumption in indoor spaces, which presents vast opportunities for smart lighting model development through automation and adaptive control. This study proposes a smart lighting system model for room environments that dynamically adapts to user presence and supports diverse light bulb types. The study analyzes energy usage while maintaining automatic light control and operational effectiveness through simulation. The system is developed using AnyLogic by integrating agent-based and discrete event simulation to model occupant behavior and manage event-driven lighting logic. It incorporates sensors, smart door mechanisms, and energy-measuring processes, all powered by solar energy and managed through battery storage. The system dynamically adjusts lighting based on occupancy, minimizing idle energy usage for the room. LED bulbs offer more promising energy efficiency, while incandescent bulbs show the highest consumption. The outcome provides a visualized simulation model for designing adaptive lighting systems and reinforces the potential to enhance energy efficiency to support sustainability in smart room applications.**

***Keywords*—Bulb; energy; light; model; simulation**

I. Introduction

In an era characterized by boosted environmental awareness and resource limitations, the implementation of efficient lighting systems has become a crucial aspect of energy management in commercial and residential buildings. With their substantial impact on electrical consumption, optimizing lighting systems is essential for reducing overall energy usage and advancing sustainability initiatives. With urbanization and increasing indoor activity, there has been a critical push towards optimizing lighting technologies [1] to enhance energy efficiency and environmental sustainability. The advent of smart room technology, powered by automation and data-driven modeling, enables efficient energy management through dynamic control of lighting. Modern intelligent lighting systems are no longer limited to manual operations; they now integrate occupancy sensors to optimize light intensity in real-time [2]. This results in a reduction of energy waste and operational costs while also enhancing environmental sustainability [3]. Conventional lighting systems, such as incandescent and halogen bulbs, though widely used, are characterized by higher energy demands and shorter lifespans. In contrast, compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs) [4] offer higher lighting efficacy, longer durability, and better energy performance. These diverse bulb types, while functionally different, collectively influence how energy is consumed in smart room environments. A significant challenge in designing energy-efficient lighting for indoor environments lies in accommodating the diverse characteristics of light bulbs such as incandescent, halogen, CFL, and LED, each with distinct energy consumption patterns and lighting efficacy.

In smart room environment, automation is transforming the management of lighting through the integration of sensing devices, energy data, and user behavior. Smart lighting systems equipped with motion sensors, ambient light detectors can dynamically control bulb power and operating time. The purpose is to ensure that lighting is delivered only when and where it is needed, thereby minimizing unnecessary consumption and improving energy efficiency. To analyze the efficiency of smart lighting systems, simulation-based modeling plays a crucial role [5], [6]. AnyLogic, a multi-method simulation tool, supports both Agent-Based Simulation (ABS) and Discrete Event Simulation (DES), enabling a detailed investigation of human-light interaction and dynamic system behaviors. These simulation paradigms are essential for mimicking real-world room scenarios that involve diverse bulb types and variable occupancy patterns. The present study leverages AnyLogic to simulate smart lighting control within a room environment, focusing on the behavioral dynamics of incandescent, halogen, CFL, and LED bulbs under various conditions.

Fig. 1 illustrates the basic structure of a smart lighting system for the room environment, which integrates motion sensors, ambient light sensors, and the energy measuring module. Each component of this structure has shown the basic strategy of reflecting real-time interactions, where automatic lighting is turned on and off based on user presence, lighting control is adjusted, and energy consumption is recorded across bulb types. This system-level visualization reinforces the need for adaptable lighting control systems that incorporate diverse bulb types for optimized energy consumption.

Despite advances in lighting control with energy-saving strategies, many existing lighting systems remain manually controlled or inadequately automated, leading to considerable energy wastage. Traditional systems often operate lights irrespective of occupancy status, resulting in excessive and

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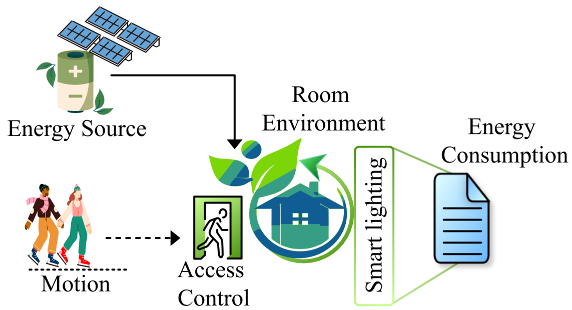

Fig. 1. Basic structure of smart lighting system for room environment.

inefficient usage. This is particularly problematic in residential and commercial rooms, where lighting accounts for a large portion of electricity energy [7], [8]. Moreover, while LED or CFL bulbs are substantially more efficient than traditional incandescent or halogen lamps, their potential is often underutilized due to a lack of an optimized structural approach. Smart lighting systems that adjust based on occupancy and ambient light offer promise but are hindered by barriers such as high initial costs, lack of integration with diverse bulb types, and limited modeling tools that can represent complex interactive behavior within smart rooms. Furthermore, real-world visualization and validation of energy savings through simulation tools like AnyLogic remains limited explored. This research addresses the gap by designing a simulation model that supports analysis of various lighting technologies within a smart room ecosystem, aiming to reduce unnecessary energy consumption and improve lighting efficiency in the room environment [9].

The rapid global increase in energy demand, coupled with environmental concerns and unattended light usage, motivates the adoption of smart lighting solutions. Since lighting constitutes a significant portion of energy consumption in room environments, adopting smart lighting controls is crucial for enhancing energy efficiency. The motivation for this research stems from the need to simulate and visualize a smart lighting simulation model that can dynamically respond to user presence [10] and ambient conditions while optimizing energy usage across different bulb types. By simulating and analyzing the performance of diverse bulb types under varying control schemes of a smart system that adapts in real-time, this study aims to provide an energy-efficient smart lighting solution adaptable to room environments and future green buildings. The study involves developing a simulation model in AnyLogic by integrating ABS and DES [11] for sensor-triggered lighting events with human behavior modeling. The room environment is modeled as an agent containing motion and light sensors that interact with diverse bulb agents. Each bulb type, such as incandescent, halogen, CFL, and LED is defined with specific wattage and bulb efficiency parameters. Simulation runs are conducted across various scenarios with differing occupancy rates, light availability, and bulb mixes. Energy consumption metrics are collected and analyzed to assess the performance and efficiency of each configuration. Accordingly, this study conveys the following contributions:

- This study provides a smart lighting system with operational process flow in room environments that serves automatic light management for diverse light bulbs.
- This study develops a smart lighting model with visualization using AnyLogic that integrates agent-based and discrete-event simulation for deployment in room environments.
- A comparative energy analysis is conducted to evaluate the performance of the proposed smart lighting systems across diverse bulb types.

In the upcoming sections, it covers the following aspects of this work. Section II provides an overview of the related studies, while Section III introduces the entire process and design of this work. Section IV presents the results and discussion of the exploration of this work. Finally, Section V concludes this study.

II. Related Work

In recent years, the increasing demand for energy-efficient lighting has intensified research efforts into smart control systems, user behavior, and advanced bulb technologies within room-based smart lighting environments. This section reviews notable studies on lighting energy optimization, modeling approaches, and performance assessments to contextualize the existing work.

Niko Gentile [12] in one work focuses on user behavior in lighting control, highlighting the role of dimming extent, interface design, heuristics, and feedback in reducing energy consumption. It identifies behavioral categories influencing energy efficiency and proposes strategies to nudge users toward sustainable habits. Though not simulation-based or bulb-specific, the study emphasizes human-centered lighting controls and estimates potential energy savings, highlighting the importance of integrating psychological and technical aspects for holistic lighting solutions. In another work, Campano et al. [13] presents a dynamic analysis of smart lighting controls based on daylight metrics and user requirements. It proposes three control systems as switch-based, dimmer-based, and sensor-driven, assessed using daylight autonomy metrics in test cells over one year. Although it does not simulate different bulb types, it effectively uses sensor-linked control schemes to reduce electric lighting energy savings. The study of Pašić and Imamović [14] compares the energy efficiency of LED bulbs against traditional ones like incandescent and halogen. Using direct energy consumption measurements, the authors establish LEDs as significantly more efficient. The work focuses on empirical comparison without simulation tools, and while it lacks dynamic modeling, it underscores the performance superiority of LEDs, which supports their integration into smart lighting frameworks for sustainable building applications. Besides, Ayaz et al. [15] proposed an urban street lighting system powered by hybrid renewable energy using solar and wind, integrating smart control for light intensity based on pedestrian and vehicle detection. The study emphasizes distributed generation and outlines practical system deployment. Although it focuses on outdoor lighting, the operational principles led by adaptive lighting control and renewable energy integration are directly applicable to indoor smart lighting simulations.

Moreover, Powers and Saad [16] presented lighting energy use in university buildings and models energy savings from retrofitting with LED lights and occupancy sensors. Using Python-based numerical simulation, the study demonstrates energy reduction and CO2 emission savings. Although it doesn't simulate bulb diversity, it emphasizes the effectiveness of sensor-linked LED systems and calculates economic payback, with a break-even point for the retrofit investment. In one study, Tsaknakis et al. [17] introduced a holistic smart building management system for elderly care, integrating lighting, HVAC, and battery storage. Using EnergyPlus for simulation, the system employs Approximate Dynamic Programming to optimize visual comfort, energy cost, and load safety. The lighting system adjusts based on daylight and occupancy. Though not bulb-specific, the integration of comfort and efficiency aligns with smart room lighting strategies in our study.

In addition, Singh and Narwal [18] conducted an audit-focused study that evaluates energy consumption in residential lighting systems and suggests LED and CFL replacements for GLS and tube lights. It lacks simulation or smart control strategies, but it emphasizes practical retrofitting approaches. This warehouse-focused study by Füchtenhans et al. [19] uses simulation to evaluate smart lighting strategies, comparing three operational schemes against conventional lighting. The system adapts to worker presence and order-picking schedules. Though specific bulb types are not detailed, LED-compatible smart systems are implied. The simulation evaluates warehouse layout, worker movement, and lighting control, offering insights into energy savings and system design trade-offs. The authors of another study, Imamguluyev et al. [20] highlighted the potential of fuzzy logic control (FLC) for optimizing lighting systems. FLC adapts illumination in real time based on occupancy and ambient light, enhancing energy efficiency. It discusses implementation challenges and presents real-world cases. Although not bulb-type-specific, the adaptive control mechanism resonates with our focus on modeling intelligent lighting systems that balance energy use and user comfort in room environments.

Most prior research focuses just on LED-based systems, specific-use contexts such as warehouses or elderly homes, or lacks integrated simulation frameworks that present real-time lighting systems. While some studies focus on real-world deployment with basic tools such as energy audits and retrofits, others utilize some modeling platforms like EnergyPlus or bespoke simulation scripts to evaluate cost and energy benefits. However, few papers holistically model lighting systems in room-level indoor environments using diverse bulb types. More critically, no studies combine agent-based simulation (ABS) with discrete-event simulation (DES) to support real-time smart lighting scenarios adaptable across CFL, LED, halogen, and incandescent bulbs. However, based on the problems identified in existing studies, the research question of this work is stated as: What type of simulation model is suitable for developing a smart lighting system, and how can ABS and DES modelling in AnyLogic effectively support real-time lighting control in room environments with diverse bulb types for energy analysis and system responsiveness? It presents a strong opportunity for the proposed study.

III. Methodology

This study introduces a simulation-based modeling view and methods for analyzing energy-efficient smart lighting in room environments supporting diverse bulb types, namely incandescent, halogen, compact fluorescent (CFL), and light-emitting diode (LED). The model is designed using AnyLogic simulation software [21], which enables a modeling approach combining Agent-Based Simulation (ABS) and Discrete Event Simulation (DES). This simulation modeling is crucial for capturing user behavior, occupancy sensors, and light sensors that control lighting conditions for the room environment. This methodology enables a comprehensive evaluation of each lighting scenario under varying usage conditions. The main design and the coordination process of energy-efficient smart lighting in room environments supporting diverse bulb types are illustrated as follows.

A. Overview of Conceptual Model for Smart Room Lighting System

Fig. 2 illustrates the proposed conceptual model for a smart lighting system designed to operate efficiently within a room environment using sensor-based automation and solar energy sources. The core elements of the model include occupants, a smart door, occupancy sensors, diverse room lights (Light 1 to Light 4), a solar energy source, a battery, a smart meter, and an energy analysis module. This system contains incandescent, halogen, CFL, and LED as Light 1, 2, 3, and 4, respectively. When an occupant approaches the room, the occupancy sensor detects their presence and triggers the smart door mechanism to open. Once the occupant enters, the system identifies the transition from an empty to an occupied state and responds by switching on the room lights. Each light is activated based on the specified capacity, influenced by sensor feedback and occupancy positioning.

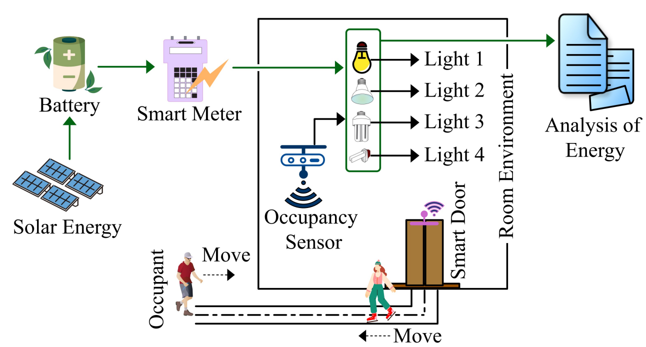

Fig. 2. Proposed model for smart lighting system in the room environment.

Energy for lighting is supplied from a solar panel system connected to a battery and charge controller. This configuration allows the room to operate on solar energy as renewable energy, reducing grid dependency. When lights are ON, a smart meter continuously records energy consumption and efficiency by providing essential data for energy analysis. This analysis helps assess lighting performance under different occupancy conditions, allowing optimization of energy usage based on real-time. Crucially, this model enables automatic decision-making. If multiple occupants are present, the lights remain

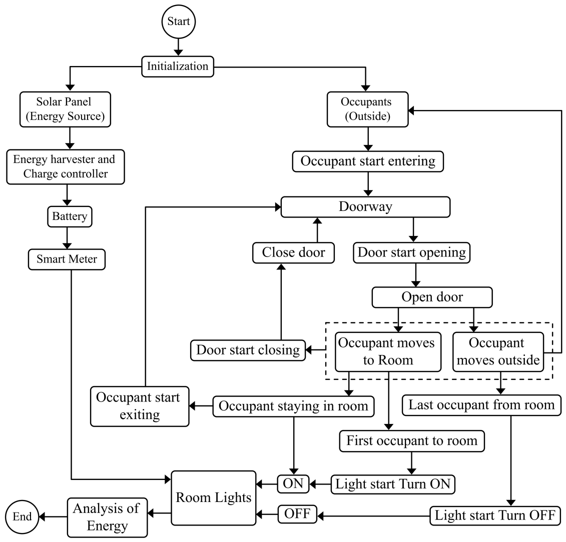

Fig. 3. Operational process flow for smart lighting system in the room environment.

ON. When the last occupant exits, the system detects the room's transition to an unoccupied state and turns off all lights, ensuring zero idle energy consumption. The proposed model supports diverse bulb types, namely LED, CFL, incandescent, and halogen, though each has distinct power characteristics. The smart meter's data, in combination with energy usage from different bulbs, enables comparison across scenarios. This allows the simulation model to assess energy usage or consumption and lighting effectiveness. The occupant's behavior, like entry, exit, and duration of stay, forms the central loop that drives the smart system, ensuring that lighting is only active when necessary. Hence, the model leverages the integration of sensors, renewable energy, and intelligent control to deliver an energy-conscious smart lighting system.

B. Operational Process Flow for Room Light Environment

Fig. 3 presents a detailed operational process flow of the smart lighting system in a room environment, capturing the chronological steps and conditional logic for lighting and door control, occupant behavior, and energy management. The process starts when occupants are outside the room. Once an occupant approaches the doorway, the occupancy sensor detects movement, prompting the smart door to open. The system marks the first occupant entering the room if no one is inside, triggering the room lights to turn ON. After entry, the door automatically closes, and the system maintains lighting as long as at least one occupant remains. During the occupant's stay, if additional individuals enter, the system tracks the occupancy count. Lights remain ON until the last occupant exits. When an occupant starts to exit, the sensor again detects motion, triggering the door to open and then close after departure. Once the last occupant leaves, the lights switch OFF automatically. This logic for the smart room ensures zero energy wastage in unoccupied conditions.

The energy required for lighting is drawn from a solar panel connected to a battery via a charge controller. This stored energy is consumed when the lights are ON, and the smart meter records the power usage in real-time. Data from the energy supplied to the lighting system is used for the energy analysis of diverse light bulb types. The system analyzes energy metrics such as energy consumption, lighting duration, and energy efficiency per bulb type. Hence, this operational flow coordinates sensor-based detection, automated door and lighting control, and intelligent energy usage analysis for room environments.

C. Visualization and Demonstration of Room Lighting Simulation Model

The smart lighting simulation model for the room environment has been developed using AnyLogic simulation software, leveraging its statechart functionality to design dynamic behaviors. Fig. 4 demonstrates the statechart for automated door control within the smart room lighting system, which plays a vital role in synchronizing user access with the lighting control mechanism. The door can exist in one of four states, namely Closed, Opening, Open, and Closing. These states are dynamically triggered by user presence and transition logic. When the door is in the Closed state, according to Fig. 4(a), the system waits for a user detection event. In this case, room lights are OFF. However, when a user approaches the entrance and detects user motion through a sensor, the door transitions to the Opening state, which is shown in Fig. 4(b). During this stage, lights remain OFF until the user starts entering. Once the door reaches the Open state, as shown in Fig. 4(c), the user is allowed to enter, and lighting control is triggered. If it is the first user, the system activates room lights based on the bulb type. As the user finishes entry, the door transitions to the Closing state according to Fig. 4(d). If additional users are detected, the door reopens. Once all users have entered and the door is re-closed, the lights remain ON as long as user occupancy persists.

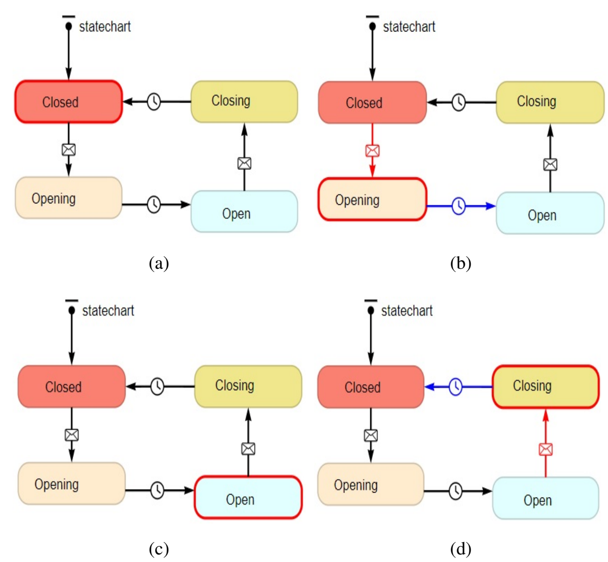

Fig. 4. Different door state transitions: (a) Closed; (b) Opening; (c) Open and (d) Closing.

Fig. 5 presents the statechart controlling user movement across four states, namely Outside, Entering, Inside, and Leaving, which influence the activation or deactivation of lighting behavior based on user activity. When the user is in the Outside state, as shown in Fig. 5(a), the room remains unoccupied, and the lighting system is OFF. Upon detecting the motion sensor, it triggers the smart door to open, and the user transitions to Entering, which is depicted in Fig. 5(b), and simultaneously activates the lighting system based on the occupancy sensor. As the user transitions to the Inside state, like Fig. 5(c), lights remain ON continuously. During this stage, if multiple users are present, the light remains ON until the last user transitions to the Leaving state. The Leaving state, as demonstrated in Fig. 5(d), is activated when a user moves toward the exit. If the departing user is not the last, the lights remain ON. However, once the last user leaves, the system transitions to Outside, automatically turning lights OFF and logging the total energy consumed.

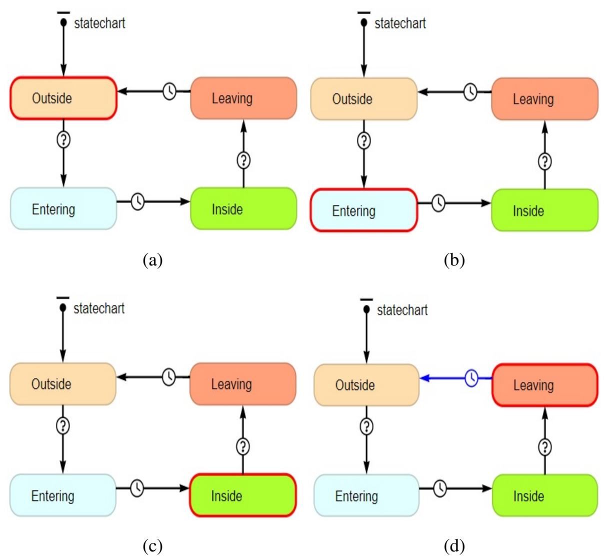

Fig. 5. User movement transitions in different cases: (a) Outside; (b) Entering; (c) Inside and (d) Leaving.

Algorithm 1 governs the smart lighting control logic by synchronizing user presence, door state, and light activation within the simulated room environment. When a user is detected near the door, it opens, updates the user state, and turns ON the lights based on the bulb type. Once inside, lights remain ON. When users exit, the door reopens, and lights turn OFF only if the room becomes unoccupied. Energy usage is logged dynamically, enabling adaptive lighting control based on occupancy and minimizing idle energy consumption.

Fig. 6, captured from the AnyLogic simulation runtime, visually represents the transitional states of a smart lighting system in a room environment, which highlights occupant behavior, door status, and lighting control through both 2D and 3D views. Fig. 6(a) and Fig. 6(b) illustrate the idle state, where all occupants are outside the room, the smart door remains closed, and the room lights are turned OFF. Thus, it minimizes unnecessary energy use. These states confirm that the system maintains a default OFF status in the absence of activity, conserving energy effectively. In another case, Fig. 6(c) shows this interaction in 2D, while Fig. 6(d) presents it from a 3D spatial perspective. These visuals emphasize the system's responsiveness to real-time human presence, maintaining optimal illumination as occupants move inward.

Algorithm 1 Smart lighting control based on door and user state transitions

Input:-

motionSensor: user detection for door functionality;
bulbType ← {LED, CFL, Halogen, Incandescent};
occupancySensor: user detection for light functionality;
roomUser: Number of users in the room;
doorState ← {Closed, Opening, Open, Closing};
userState ← {Outside, Entering, Inside, Leaving};

Output:-

lightStatus ← {ON, OFF}; energyUsage: energy consumption for different types of bulbs;

```
Initialize States
Set doorState ← Closed;
Set userState ← Outside;
Set lightStatus ← OFF;
Set roomUser ← 0;
while Simulation is running for entry event do
    if motionSensor = TRUE AND doorState = Closed then
        doorState ← Opening
        Activate door opening mechanism
        Wait for door open time duration
        doorState ← Open
        userState ← Entering
        roomUser ← roomUser + 1
        Call Turn_ON_Lights(bulbType)
        lightStatus ← ON
    end if
end while
while Transition to Inside do
    if userState = Entering AND Light_ON = TRUE then
        userState ← Inside
        Activate door closing mechanism
        doorState ← Closing
        Wait for door close time duration
        doorState ← Closed
    end if
    if userState = Inside AND user initiates exit AND doorState = Closed then
        doorState ← Opening
        Activate door opening mechanism
        Wait for door open time duration
        doorState ← Open
        userState ← Leaving
        roomUser ← roomUser - 1
        if roomUser = 0 then
            Call Turn_OFF_Lights()
            lightStatus ← OFF
            Record energyUsage in log
        end if
        userState ← Outside
        Activate door closing mechanism
        doorState ← Closing
        Wait for door close time duration
        doorState ← Closed
    end if
end while
```

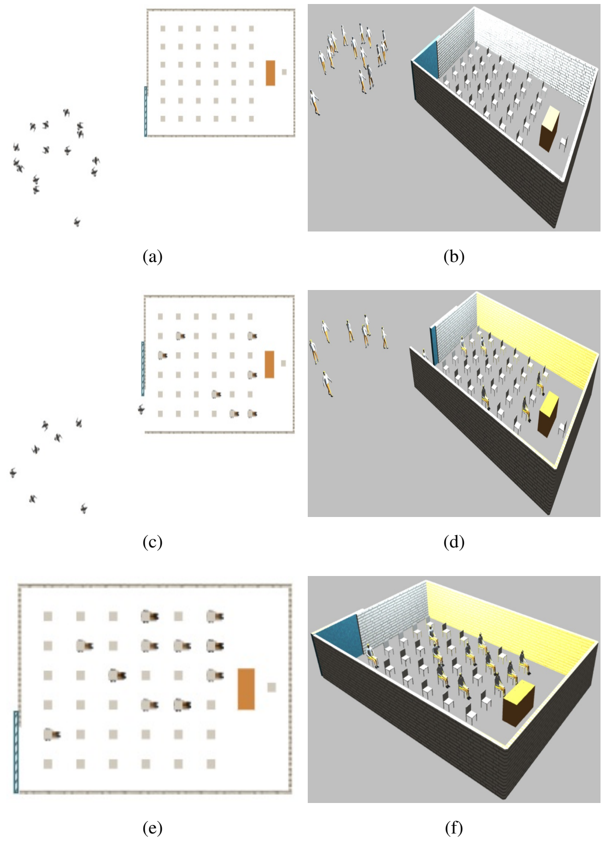

Fig. 6. Graphical layout: (a) Users are Outside when Door is closed in 2D; (b) Users are Outside when Door is closed in 3D; (c) Users are Entering when Door is opened in 2D; (d) Users are Entering when Door is opened in 3D.; (e) Users are InSide when Door is closed in 2D and (f) Users are InSide when Door is closed in 3D.

In this case, when a user is sensed at the door, and it opens, then the user enters the room, and automatically it turns ON the light bulb. Once all occupants have fully entered the room, the door closes again, and the lights remain ON, as depicted in Fig. 6(e) in 2D and Fig. 6(f) in 3D. This state reflects the active condition of the room, where lights are sustained to ensure visibility. The consistent light ON status confirms the system's awareness of active room use. These figures collectively showcase a seamless interaction between user presence, automated door control, and lighting behavior. This sequence of views validates the responsiveness and efficiency of the smart lighting system, where occupant-driven automation ensures both user convenience and optimal energy usage through intelligent control logic.

IV. Results and Discussion

To evaluate the effectiveness of the proposed smart lighting system in the room environment, a simulation model has been developed in AnyLogic software. This model allows for the simulation of basic scenarios of energy usage service and energy processing across different light bulb types. This section illustrates the results and analysis obtained from the simulation of the proposed smart lighting system for the room environment. The focus of the analysis is to assess the system's visualized responsiveness, energy usage, and efficiency based on occupancy patterns and diverse light bulb types. The smart lighting logic is triggered by user movements and the simulation dynamically adjusts the lighting status based on room occupancy. Door and user movements are governed by agent-based logic, while lighting events and energy analysis are modeled through discrete event simulation. The study demonstrates how intelligent control logic contributes to energy efficiency. The key performance metrics, namely energy usage, lighting duration, and bulb-wise energy profiles, are recorded. The output visualizations and plots extracted from the simulation runtime enable a comparative assessment of energy usage and efficiency in the model. This evaluation highlights the system's ability to conserve energy while demonstrating the effectiveness of adaptive lighting control supported by simulation.

A. *Results*

The simulation model for this work has been developed and executed using AnyLogic 8.9.4 Personal Learning Edition on a system configured with Windows 11, 64-bit, running on HP LAPTOP-2DHIQ60K. The machine is equipped with a 13th Gen Intel(R) Core(TM) i7-1355U processor (1.70 GHz) and 20.0 GB RAM, providing a robust environment for real-time simulation and visualization. The simulation has leveraged the modeling principles of agent-based simulation and discrete-event simulation to manage sensor inputs, door transitions, and lighting responses. Runtime visualizations have been generated for both 2D and 3D environments, and energy consumption data has been recorded through integrated smart metering components in simulation.

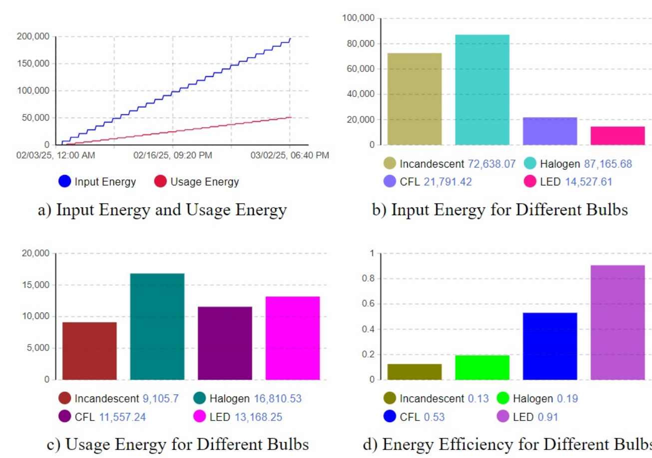

Fig. 7. Analysis view for diverse bulb types of the lighting system.

As illustrated in Fig. 7, the approach of this work enables the assessment of how user behavior influences lighting energy consumption across different bulb types, contributing insights into energy efficiency. During the simulation runtime, this model utilized incandescent, halogen, CFL, and LED bulbs, with power ratings of 50W, 60W, 15W, and 10W, respectively. In this case, Fig. 7(a) depicts a comparative analysis of the input energy and corresponding usage energy over a span of simulated days. The input energy, harvested from solar sources and stored in a battery system, steadily accumulates, while the usage energy fluctuates based on user presence and lighting demand. It shows that the energy usage increases sharply during occupancy hours and illustrates that the input energy remains consistently higher than the energy usage for active light bulbs, indicating a surplus from the renewable supply. When the room is unoccupied, usage energy remains flat, validating the effectiveness of the smart lighting system in conserving energy for the overall pattern. This adaptive behavior ensures that only the necessary energy is consumed, with the remaining stored in the battery for future use, reflecting sustainable energy management.

Fig. 7(b) shows that this work has drawn an analogy of the input energy requirements for each type of bulb, namely LED, CFL, Halogen, and Incandescent, in a smart lighting system. The LED bulbs require the least amount of energy input, followed by CFL, Halogen, and Incandescent in ascending order. The ranking of the required energy aligns with the known wattage demands of these bulbs, which reflects the cumulative energy drawn from the energy source. In the simulation model, input energy is measured during the occupancy activity, ensuring an acceptable comparison. However, it reinforces the energy advantage of LED lighting in smart environments. Notably, the high energy input for incandescent and halogen bulbs suggests limited suitability for sustainable operations, especially in solar-powered setups. This insight can guide bulb selection for energy-conscious environments, emphasizing LEDs as the optimal choice for smart systems.

In Fig. 7(c), this work illustrates the actual energy usage or consumption by each bulb type over the simulation period for the smart lighting system. LED bulbs show the better energy usage, reinforcing their efficiency. CFLs follow with moderate usage, while Halogen and Incandescent bulbs exhibit substantially higher consumption levels. The data is directly related to the duration of light ON and the wattage rating per bulb. However, it specifically captures energy drawn during active lighting when occupants are present. It emphasizes the real-time energy cost incurred during system operation. The consistent interval between the usage energy of LEDs and other bulbs highlights their operational efficiency under dynamic conditions. It supports the case for deploying LEDs in environments with frequent user movement, where lights may toggle ON/OFF multiple times a day. The system's ability to minimize consumption without sacrificing functionality is demonstrated clearly through this usage pattern.

Fig. 7(d) presents a normalized analogy of energy efficiency across bulb types. Energy efficiency is defined here as the ratio of the useful output energy of light to the input energy required. The results show that LED bulbs achieve the highest efficiency, around 0.9, closely followed by CFLs. Halogen and Incandescent bulbs lag behind significantly, with incandescent efficiency being the lowest efficiency below 0.15. It reinforces the technological superiority of LED lighting in terms of both performance and sustainability. It validates the system's energy-saving claims by quantitatively showing how much energy is effectively utilized or wasted in smart room environments. These results support a significant outcome of the model that smart lighting systems, especially those powered by renewable energy sources, should prioritize high-efficiency bulbs to maximize overall system performance and minimize energy loss.

B. Discussion

This work demonstrates that the proposed smart lighting system, developed using AnyLogic with ABS and DES, effectively adapts to occupant presence while supporting diverse bulb types. Simulation graphs show that LED bulbs consume the least energy and offer the highest efficiency, while incandescent bulbs are the least efficient. Real-time automation, occupancy-based control, and energy logging validate the system's responsiveness and sustainability. The model also integrates solar energy and smart components, highlighting significant improvements in energy usage.

TABLE I. COMPARATIVE EVALUATION

Ref.	Simulation Tool	Supported Bulbs	Modeling Approach	Energy Efficiency	Key Advantage
[14]	None (Empirical study)	LED, CFL, Incandescent	Energy consumption	LED showed high savings	No automation or simulation model
[18]	None (Energy audit)	LED, CFL, GLS, Tube lights	Audit & replacement strategy	Recommend LED as most efficient	No dynamic modelling
[19]	Custom Simulation Model	SLS, Conventional light	Simulation-based operational strategy	SLS reduced warehouse energy costs	Lack of renewable energy integration
[22]	None (Arduino IDE)	LED, CFL	Optimisation strategy	LED is used for saving energy	No energy tracking or dynamic simulation
Our work	AnyLogic 8.9.4	LED, CFL, Halogen, Incandescent	ABS and DES modelling approach	LED most efficient, room context driven automatic light control	Real-time automation, 3D visualization, renewable energy integration, multi-bulb energy profiling

Table I presents a comparative evaluation of the functionalities and features of the presented smart lighting system with some existing studies. It shows that previous works either used basic empirical methods, manual audits, or lacked real-time automation and simulation. Most of them supported limited bulb types and did not incorporate renewable energy sources or simulation modeling techniques. However, the presented simulation model utilizes AnyLogic 8.9.4 with the ABS and DES approach, simulates four bulb types, and integrates smart automation with solar energy. It also supports 3D visualization and real-time behavior modeling. These advantages collectively demonstrate the superiority of the presented simulation model in terms of functionality and energy efficiency in smart lighting systems for room environments, compared to earlier research.

V. CONCLUSION

This work presents the design and simulation of an intelligent lighting control system for room environments using AnyLogic, integrating agent-based and discrete event simulation. The system supports diverse light bulbs and responds dynamically to user presence, optimizing energy usage through sensor-based automation and control logic. The simulation results reveal that the proposed smart lighting model effectively minimizes energy consumption by adapting to user occupancy patterns. Among the evaluated bulb types, namely LED, CFL, Halogen, and Incandescent, LED bulbs consistently required the least energy input and achieved the highest energy efficiency, followed by CFLs, while halogen and incandescent bulbs consumed significantly more energy. The system successfully automated lighting control and energy logging using the smart door and motion sensor interactions. Idle energy use can be eliminated when all lights turn OFF and the room becomes unoccupied in a room environment. This work visually represents the transitional states of a smart lighting model in a room environment, which describes occupant behavior, door status, and lighting control in both 2D and 3D views at AnyLogic simulation runtime. This work contributes a dynamic, simulation-based approach to energy-efficient lighting design for a room. It supports valuable insights for designing energy-efficient building automation decisiveness and serves as a baseline for deploying adaptive lighting strategies in modern smart rooms and green buildings. The study is limited to simulation-based modeling only in single-room environments and is built on the assumption of optimal sensor performance without the influence of environmental noise. In the future, this work has the potential to broaden the model to encompass multi-room layouts, incorporate variations in weather conditions, and explore cost optimization in the context of real-world indecisiveness.

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