Smart Streetlight Automation Using Iot for Sustainable Urban Management

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Abstract
This paper presents the development and implementation of a Smart Street Lighting System using Internet of Things (IoT) technologies. The system employs an Arduino Uno microcontroller and an ESP8266 Wi-Fi module to automate streetlights based on ambient light levels and manual overrides. A Light Dependent Resistor (LDR) and a push-button are used as input components, and ThingSpeak is used as the cloud platform to visualize and monitor sensor data in real time. The project aims to optimize energy consumption and enable remote monitoring proficiencies. The complete system was developed and tested in a simulated environment using TinkerCad and with ThingSpeak.

Keywords: Smart Street Light, IoT, Arduino Uno, LDR Sensor, ThingSpeak, Energy Optimization & ESP8266.

1. INTRODUCTION

Future urban expansion needs advanced, cost-effective, and energy-efficient solutions. Old-style street lighting installations lack scalability, are naturally functioned manually, also consume exorbitant amounts of power. Automation allowed by the Internet of Things (IoT) offers numerous benefits, particularly as modern cities as well as sustainable urban development gain popularity. The paper shows a workable smart street lighting idea that can be scaled for implementation by utilizing cloud-based analytics and embedded technologies. At the same time, it assesses the return on investment, administrative choices, and financial consequences for local governments. This paper presents a practical approach to smart street lighting by leveraging embedded systems and cloud-based analytics. It also takes a closer look at the monetary aspects—such as cost-effectiveness, decision-making strategies, and potential return on investment—for city planners and municipal leaders considering large-scale implementation.

2. Technologies Used

- The Internet of Things (IoT) connects devices to gather, share, and act on data. Sensors in this structure detect environmental levels of illumination and transmit data to a cloud server over an internet connection. IoT enables continuous surveillance and remote decision-making, which are essential for sustainable the entire city management.

- The Arduino Uno is a free and open-source Arduino-based microcontroller built around the ATmega328P. It provides digital as well as analog I/O pins that link to the specified system's sensors and actuators. In the system that we have, it reads the LDR value, reads the push button status, and manages the relay-based switch logic.
- ESP8266 Wi-Fi Module: The ESP8266 is a low-cost Wi-Fi module used to connect the Arduino to the internet. It uses AT commands for serial communication and HTTP GET desires to send data from sensors to ThingSpeak.
- ThingSpeak IoT System: ThingSpeak is a freely available Internet of Things (IoT) platform that collects, stores, as well as displays information from sensors in real time. It can run MATLAB-based analytics, graphs, & widgets. The project is used in our system for maintaining records of LDR values, pushbutton states, along lighting conditions.
- Sensors and Actuators: LDR (Light Dependent Resistor) Detects ambient light intensity, Relay Module Acts as a digital switch for streetlight operation, and Push Button serves as a manual trigger for override.

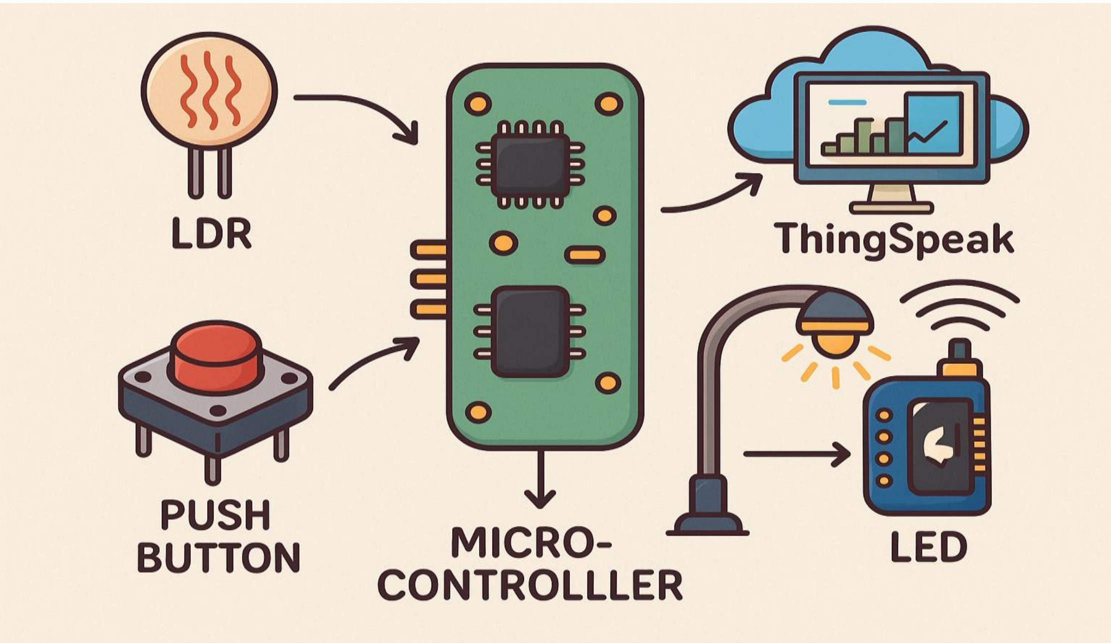

Figure 1: Block diagram of a smart street lighting system using a microcontroller, LDR, push button, LED, and Wi-Fi module for cloud-based monitoring and control via ThingSpeak.

Figure 1 depicts the IoT-based automation process: Sensing → Decision → Connectivity → Cloud → Insight → Management.

It serves as the foundation of the whole effort, demonstrating how low-cost microcontroller setups may result in enormous-scale energy conservation and intelligent city management whenever utilized alongside cloud-based technologies.

3. Need For the System

Modern cities suffer from inefficiencies in power usage due to outdated infrastructure. According to the International Energy Agency (IEA), nearly **19% of global electricity consumption** is attributed to lighting, and a significant portion is wasted due to manual or fixed-timer operations of streetlights. Moreover, remote or poorly maintained areas often lack real-time monitoring.

- Problems in Existing Systems: Manual operation is inconsistent and error-prone, timed lights don't adapt to changing weather or seasons, Energy is wasted due to lights remaining ON in daylight & no real-time fault detection or usage analytics. Figure 2 shows the
Pictorial comparison of traditional and smart lighting systems.
- Example: In cities like Chennai and Delhi, studies showed that 30–40% of streetlights remain ON during the day due to poor automation and manual negligence (Source: TN Energy Department Report, 2022).

Figure 2: Pictorial comparison of traditional and smart lighting systems

4. How This System Solves the Problem

- This Smart Street Lighting System introduces automation using real-time light sensing and cloud connectivity. The LDR sensor accurately detects ambient light, and the Arduino processes this input to control lights only when needed. The push button allows local override.
- Key Benefits: Energy is used first once essential → Decreases power bills, Real-time monitoring → Enables fault detection & predictive maintenance & centralized dashboard on ThingSpeak → Aids authorities in designing and progress handling.
- By replacing physical routines with sensor-driven results, this structure minimizes human error, decreases functioning costs, and rises system responsiveness.

5. Interpretation From the Management Perspective

This IoT system isn't just a technological solution—it's a model for efficient urban resource management. From a management perspective, it introduces **cost control, operational efficiency, stakeholder accountability, and data-driven decision-making**.

Figure 3: "Smart urban management through IoT-driven cost and energy efficiency.

6. Objectives of the Study

- To design and simulate a smart street light system using Arduino and IoT with required sensors.
- To monitor the system remotely using ThingSpeak.
- To evaluate the energy savings and cost efficiency over traditional systems.
- To present a managerial analysis including feasibility, scalability, and sustainability.

7. System Architecture and Component Overview

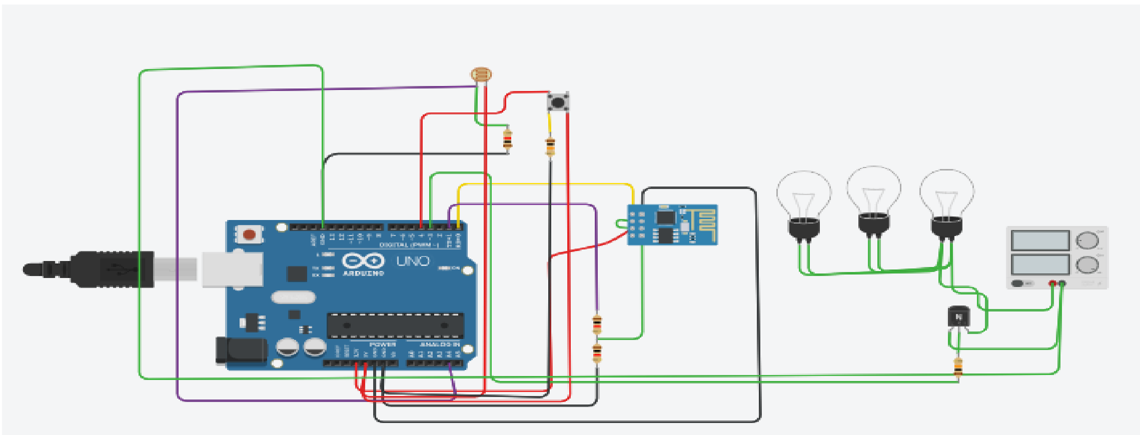

Figure 4: The entire designed System model

Figure 4 shows the entire designed model of the system & Figure 5 shows the same design in the schematic view. The lists of the hardware components are:

- Arduino Uno: Foremost microcontroller for processing inputs also controlling outputs.

- ESP8266 Wi-Fi Module: Links the system to the internet and connects with ThingSpeak.
- LDR (Light Dependent Resistor): Senses light intensity.
- Push Button: Manual override feature.
- Relay Module: Switches streetlight bulbs.

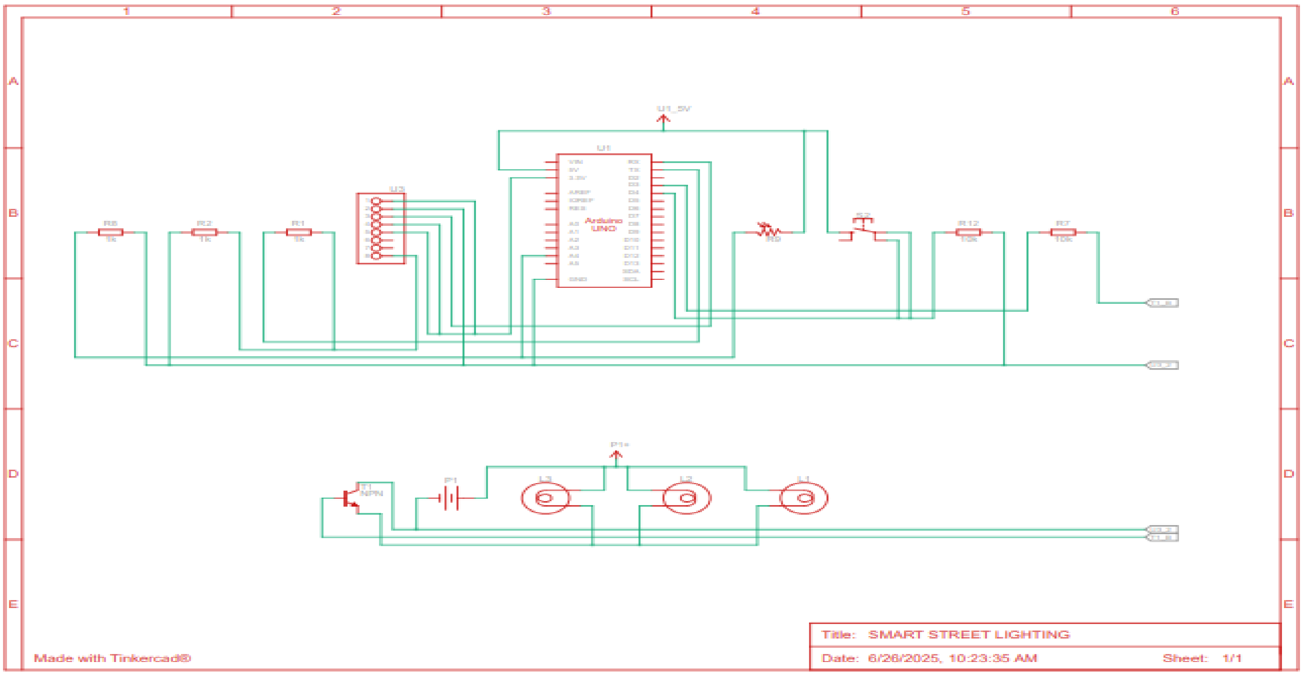

Figure 5: Schematic view of the designed model

LDR resistance decreases as light increases. This affects the voltage division at the analog input (A4). In darkness (less light), voltage increases. LDR value ranges from 0 to 1023, corresponding to the voltage range from 0 to 5 volts. LDR > 500 → LIGHT TURN ON (Moderate light intensity). A simple Code Logic (for simulation checking purpose, the value of 500 is given, in the real-time, the value will differ: if (ldr_value > 500 || buttonState == HIGH) ight,HIGH);

The list of Software and Platforms:

- ThingSpeak IoT Platform: Data visualization and cloud analytics.
- Tinkercad Simulator: Design the model and code based on our requirement and simulate hardware virtually.

Connectivity: The ESP8266 module is programmed using AT commands to link to Wi-Fi also send HTTP GET requests to ThingSpeak. Sensor data is shown in real-time, and the light status is updated dynamically.

8. Working Principle

The system continuously reads light intensity through the LDR. If light levels fall below a defined threshold (or a button is manually pressed), the Arduino activates a relay to turn ON the streetlights. The data (LDR value and button status) is sent to ThingSpeak for remote monitoring. This process repeats in cycles with real-time updates to the cloud.

9. Results And Discussion

Simulated results on ThingSpeak showed real-time updates of:

- LDR readings fluctuating with light conditions.
- Button state switching manually.
- Light condition responding to either sensor or manual trigger.

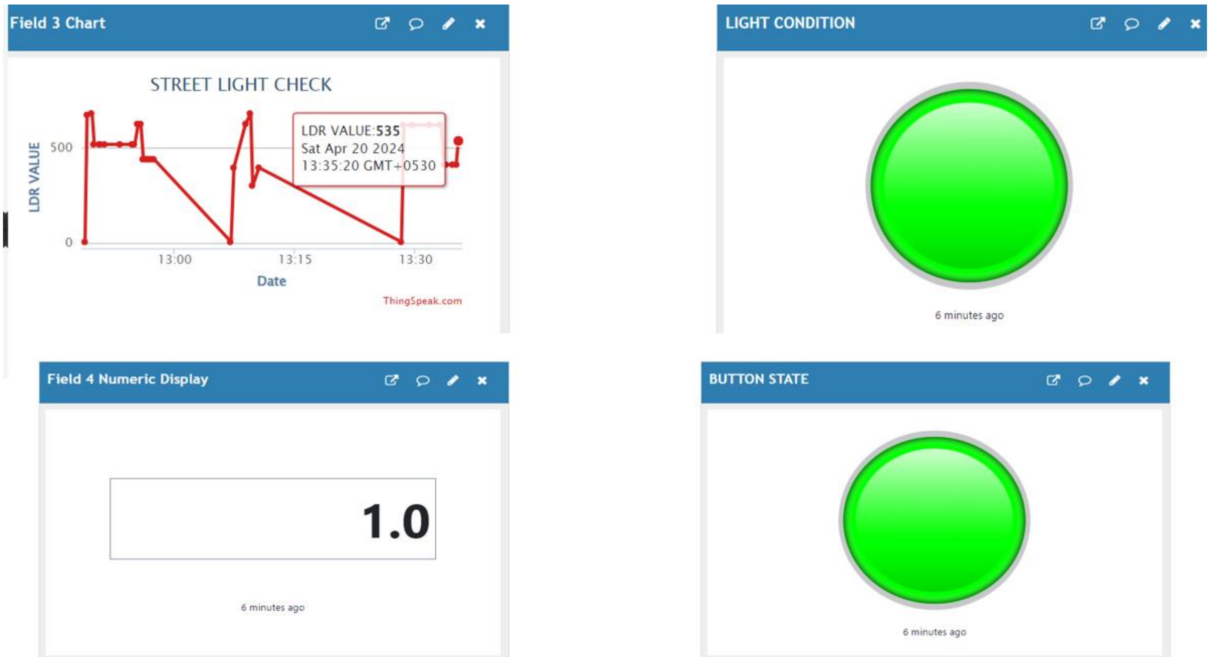

Figure 6: ThinkSpeak Monitoring dashboard of the designed system

Figure 6 shows the ThinkSpeak dashboard for monitoring the designed system. ThingSpeak is configured with fields to monitor. Field 3: LDR Value, Field 4: Button Status & Field 5: Light Condition. The dashboard includes a live chart, numeric displays, and status indicators. It allows for easy interpretation by both technical personnel and city administrators.

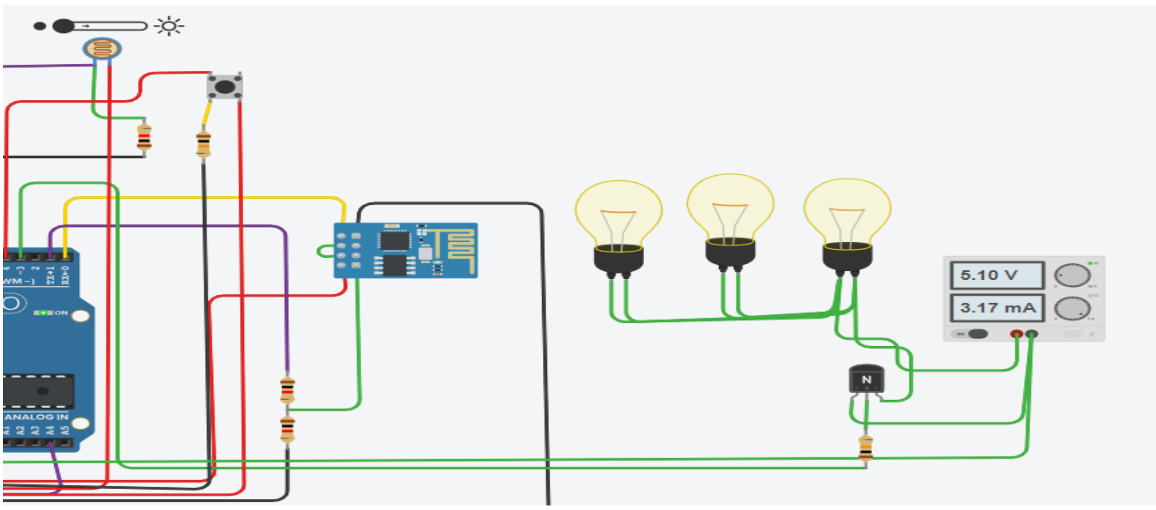

Figure 7: Street light or the Lamp turned on

Figure 7 shows the Lamp turned on as per our requirement. The system operated reliably in simulation, with consistent cloud updates and actuation.

10. Swot Analysis

Table 1: Strengths and weaknesses

Strengths	Weaknesses
Reasonable to implement and can scale for city-wide use	Depends on Wi-Fi; unstable networks can delay updates
Easy to monitor data from wherever using the cloud	Delay in response when switching physically via the push button

Table 2: Opportunities and Threats

Opportunities	Threats
Can be expanded to connect with larger smart city systems (e.g., traffic, weather)	Risk of data leaks or attacks due to poor cybersecurity setups
Can join in renewable energy sources like solar panels	Hardware may be damaged over time deprived of proper maintenance

From tables 1 & 2, the analysis highlights that the system is strong in affordability and flexibility, but it also emphasises potential delays and cybersecurity issues. For policymakers and city managers, this table helps quickly evaluate the feasibility and risk of scaling such solutions.

12. Real-Time Workflow Example

Imagine that around 6:30 in the evening, when the natural light fades, the LDR sensor detects a decrease in light. The Arduino evaluates this data and concludes that the surroundings have come to a point where lighting is required. As a result, it engages the relay, which turns on the lamps. Figure 8 depicts a broad picture of the actual time operation. If the LDR sensor malfunctions / requires restoration, an emergency button is provided as an alternative method. This manually operated override allows users to switch on the lighting even if the light sensor fails, therefore boosting dependability and continuous operation. Whenever the light is switched on, whether it is manually or automatically, the ESP8266 sends this information—along with LDR readings as well as pushbutton status—to the ThingSpeak cloud-based system. The dashboard replicates the real-time state: a circle in green indicates that the light is on, followed by animated graphing of LDR values. Authorities or urban planners may watch this from anywhere and make swift choices or maintenance calls as needed. This demonstrates the system's ability to integrate automation, visualisation of data, with decision assistance.

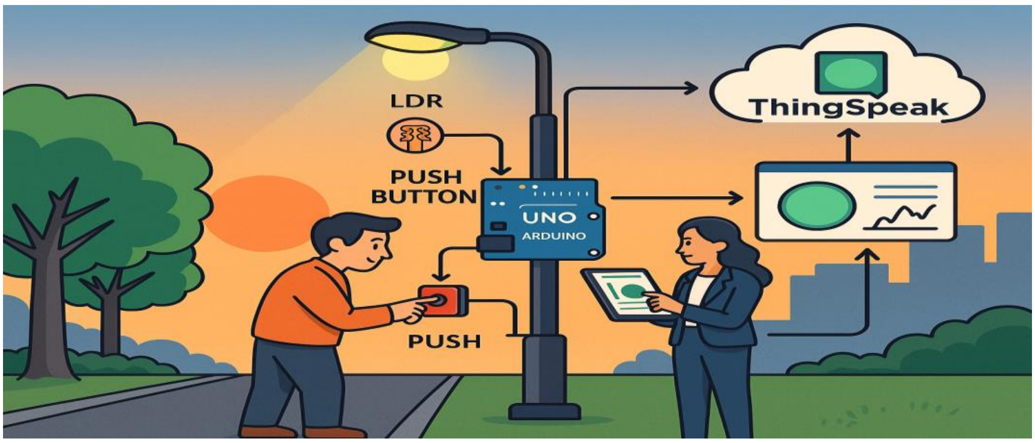

Figure 8: A general view

13. Business Model Canvas (BMC)

The Business Model Canvas delivers a framework to scale this project into a amenity or product offering:

- Key Associates: Arduino/IoT vendors, direction bodies.
- Main Actions: Fixing, monitoring, and maintenance.
- Worth Proposition: Energy-efficient, Economical, remotely tracking illumination
- The client categories include smart city managers, panchayats, as well as urban developers.
- Revenue streams include contracts with governments and dependent upon subscriptions smart services.
- The pricing structure includes equipment, deployment, and cloud-based services.

14. Key Performance Indicators (Kpis)

To benefit from tracking the efficiency also productivity of the smart lighting system, the subsequent KPIs are recommended:

- Energy Saved (kWh/month): Direct metric of environmental also financial saving.
- Physical Override Occurrence: A Higher frequency might suggest sensor issues.

These KPIs aid in developing an operational assessment of the system over time, which directs choices and enhancements.

15. Future Scope

- Incorporation by means of solar panels, as shown in Figure 9
- Usage of motion sensors to detect pedestrian/vehicle movement, as shown in Figure 10
- Mobile app control, as shown in Figure 11
- Integration with centralized urban dashboards.
- Usage of a better algorithm for rapid action from the real-time data.

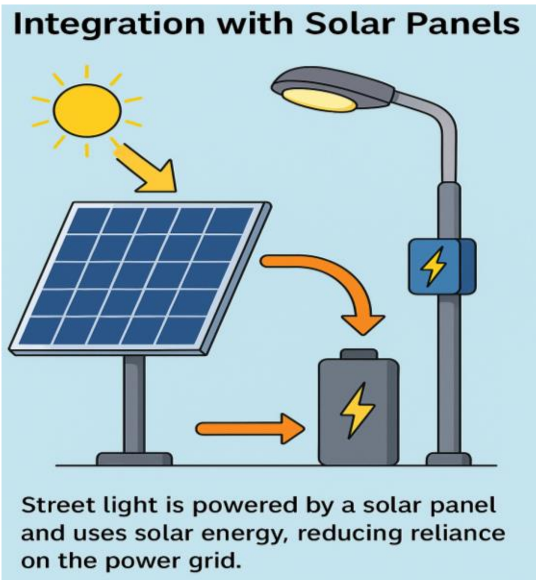

Figure 9: Solar-powered smart streetlights allow supportable, energy-efficient night-time lighting.

Figure 10: Motion-activated smart streetlights illuminate only when walkers or automobiles are sensed, guaranteeing effective energy usage

Figure 11: Approved workers controlling urban smart lighting remotely via mobile app for well-organized city illumination.

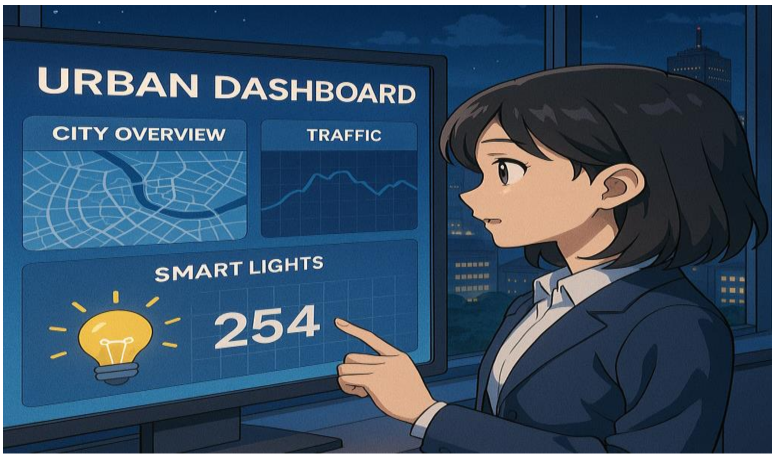

Figure 12: "Centralized urban dashboard allowing real-time monitoring in addition to control of smart street lights across the entire city.

16. Conclusion

The designed system validates an affordable, smart lighting key combination hardware simplicity and cloud intelligence. It not only decreases power usage but then again also provisions data-driven decision-making. From a managerial perspective, it signifies a feasible investment with a high return, pushing the envelope of urban sustainability.

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