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ORIGINAL CONTRIBUTION

# Economic and Environmental Impact of Energy Efficient Design of Smart Lighting System

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**Abstract** Smart cities and intelligent technologies are changing and modernizing civilization. Population growth demands the development of intelligent infrastructure for sustainable life. With the proliferation of urban into metropolitan, the utility of street lights has increased substantially, leading to high energy demand. The conventional street lighting system consumes much energy compared to the intelligent lighting system. Many studies have proposed different street lighting systems for energy saving and reduced financial burden. Light Emitting Diode (LED) was initially employed in street lighting systems to reduce power consumption. Innovative technologies with the LED street lighting system have enhanced the potential to conserve more energy. In this paper, an adaptive part-night lighting system and traffic-aware street lighting system have been proposed and implemented on the university campus. Two types of traffic-aware systems, GPS sensors, are discussed and compared with different lighting systems, whereas PIR sensor street lighting system is implemented in the testbed. These systems control the illumination of LED streetlights upon detection of vehicles and pedestrians. Power consumption, economic accountability, and environmental impact caused by various street lighting systems have been discussed to endeavor sustainable utility. Cost analysis and power consumption analysis have been carried out for six months. In addition, the installation cost of LED streetlights and various intelligent street lighting systems have been compared for future projects. Compared to the conventional lighting system, the total cost saving of 96% can be achieved by using traffic-aware smart LED and emission of $CO_2$ can be reduced by 96.24%. The smart street lighting system is eco-friendly and could provide a better-quality lighting system in the city.

**Keywords** Energy saving · Power consumption · LED · Smart lighting system · PIR sensor · GPS · Part-night lighting · Emission

## Introduction

Since the evolution of streetlights has been introduced in the roadway system, the cost and power consumption of streetlights have drawn the attention of the government and scientists. With the current situation, there are approximately three hundred four million street lamps are installed worldwide, estimated to reach 352 million by 2025[1]. A conventional lighting system indeed illuminates one-third of the roads around the world. The street lighting system is an integral part of the city's infrastructure and the utmost requirement for public safety. India uses under 1% of its total energy for public lighting. However, according to the currently available data, India's electricity consumption is increasing by 7% while public lighting systems are increasing at a 10% pace. India uses 7,753 GWh for public lighting. A 30% reduction in energy use through efficiency improvements can save 2,326 GWh of power. According to this, annual $CO_2$ emissions may be reduced by up to 1.9 million ton [2]. To pull out the city's financial plan from the limited

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source of energy systems, cities must develop an energy-efficient plan to secure the energy distribution. Sustainable technologies must be adopted to decrease energy consumption and improve residents' visibility [3]. Due to its high efficiency, prolonged product lifespan, and recyclable nature, the widely accepted light-emitting diode (LED) technology has demonstrated a way for efficient energy consumption solutions. High luminous efficacy, reliability, controlling illumination, and emission of desirable colors, these qualities exhibit as a substitute for conventional streetlamps like high-pressure sodium (HPS) for street lighting. Moreover, it is estimated that instead of using quality High-Pressure Sodium (HPS), a simple LED reduces energy consumption from 60 to 31% when applied at multi-stage light-dimming activities [4]. Although energy generation is primarily drawn from non-renewable energy sources (NRES), a significant constituent of global warming. In [5] suggested the intelligent control method for controlling the light and placement of sensors. They suggest that the correct location of sensor placement can save 24.5% of energy. In [6] suggest a novel control method for the lighting system. The experimental results indicated that the proposed Wi-Fi-based control method could save 93.09 and 80.27% energy compared to static and PIR sensor-based methods. The ideology behind the installation of smart technologies with LED street lighting systems was introduced by many researchers in their respective fields[7][8][9]. The replacement of first-generation streetlamps with LED has benefitted.

Many researchers in [10–13] have already analyzed the lighting system by replacing conventional lamps with LED streetlights. In [14] presented a soft computing-based energy-efficient street lighting system. The suggested model was executed for the residential area. The results were compared for various scenarios and different seasons. The results show that the suggested framework has 34% energy-saving capability.

Moreover [15], [16] shows the traditional method of estimating cost investment in LED street lights with traditional street lighting. In [17] and [18], energy saving can be achieved only through a part-night lighting system. Furthermore, in [19]**,** energy consumption is achieved by sourcing streetlights with solar power. In [20], multi-sensors are used in street lights to adjust their brightness. Various authors used smart technologies to suppress energy consumption and installation cost; however, they lack a suitable methodology to run streetlights effectively and efficiently. In [21] suggested the renewable-based energy management strategy for providing and maintaining the lighting system in the smart city of Iran.

In this paper, a time-based lighting system has been proposed which reduces the problem of overconsumption of electricity and helps to minimize the emission of $CO_2$. Furthermore, the traffic-aware system has been proposed and implemented in the testbed. In this system, the embedded smart sensor depends upon the traffic flow and hence controls the brightness of the streetlights. Ultimately, the various LED lighting systems have been compared against their power consumption, installation cost, and carbon emissions. Thus, this study deeply analyzes these smart lighting systems' technicality and economic feasibility. The study is implemented on a university campus. The campus is an integral part of the city. Therefore, it is the best place to apply experimental technologies. The campus includes streets, pedestrian paths, gardens, buildings, and parking lots. There are around 1050 streetlights on the campus, which is placed over 4.67 $Km^2$. However, the gathered data with 36 streetlights are a fragmented campus area with a 750 m road length for the convenient study.

This paper is divided into seven sections; in Sect. "Street Lighting System," a brief description of different lighting systems is discussed. In Sects. 3 & 4, the smart street lighting systems have been discussed, and the traffic flow for seven days of the week has been recorded. Further, a smart light methodology has been introduced in Sect. "Methodology" based on the traffic flow. Moreover, in Sect. "Results and Discussion", relevant graphs and tables have shown the results of the energy consumption, cost analysis, payback period analysis, and installation cost of different smart LED lighting systems. $${CO}_{2}$$ emission analysis has been discussed in the section. Finally, in Sect. "Conclusion", the paper concludes based on the above-mentioned analysis.

## Street Lighting System

With the growing advancement in street light technology, different adoption of streetlights has encouraged the users' comfort and safety. The main objective of installing streetlights is to illuminate the streets and prevent unusual driving or pedestrian accidents [22]. As global warming has increased over the years, climatologists have experienced unexpected weather changes. These changes, like fog, dust, and smoke, are caused due to air pollution, but dust particles in the air reduce visibility [19]. Therefore, we require an optimized power system technology for streetlights to balance the economy and visibility on streets. As in India, power equality remains asymmetrical [20]. The energy consumption and cost estimation of different lighting systems have been proposed to maintain equality between demand and supply. To maintain high visual comfort for the travelers and to perceive safety provided by the new operations. These operations are carried out from 18:00 to 6:00 (12 h). For the convenience study, the busiest streets are considered during night hours.

### High-Pressure Sodium

The High-pressure sodium (HPS) lamp emerged as the most victorious commercial streetlight to perform a single feature. The principle of sodium lamps is based upon the discharging of electrons in the medium of sodium vapors. Among many alkaline metals, the most successful light-emitting source comes out to be sodium metal[23]. The first successful luminous efficacy of the HPS lamp encourages scientists to advance technological development in different lamps with better efficiencies [24]. Energy consumption by the middle-range HPS lamps is about 30% to 35% of power input which utilizes visible light. Moreover, approx. 70% to 65% of energy is wasted in heat and other wastages [25]. However, these conventional streetlights failed to perform:

- Communication and interconnection with various intelligent devices
- Control and computational processes
- Management and automation features.

### Light Emitting Diode (LED)

The first light-emitting diode (LED) was available commercially in the late 1960s. The evolution of LED technology brought a replacement for other white lights available in the markets [20]. The LED luminous efficacy has raised its bar from a few lumens per watt [4] to more than 250 lm/W. Rapid growth in LED light causes the replacement of the conventional lamp. Moreover, integrating smart devices with LED consumes less energy and reduces pollution. The LED light has an advantage over other traditional lamps in correlated color temperature (ranges from 2540 K to 10,000 K) [20]. In contrast to conventional lamps, LED's primary approach was energy-saving, with a more significant life span of 25,000 to 100,000 h [21] than others, smaller in size [22], better performances, and more reliable [23].

### Part-Night LED Lighting System

The flexibility of LED lights has shown an effective operation; to conserve energy, minimize the cost, and control light pollution that severely impacts the environment and human health [26]. A part-night lighting system is primarily a time-based lighting system that is used to reduce luminance at a particular time. It can reduce energy consumption by 40 to 60% compared with the conventional timing of LED streetlights. The dimming strategy is not feasible to apply to the traditional lamp because it's based on timing which can be set according to our needs. However, the study reveals that the part-night system is independent of traffic flow, which indicates that the energy consumption is constant throughout with variable traffic flow [27]. The manipulation in the dimming strategy of the LED streetlight can be categorized into four phases of the night. This observation was carried out on the campus streets of Street Aligarh Muslim University, Aligarh, UP.

### Part-Night Operation

The part-night operation is taken into four different times, and it is divided into 4 phases. The different phases are discussed here; in phase 1, from 6:00 p.m. to 9:00 p.m. the streetlights are 20% dimmed (brightness is decreased to 80% from 100%). In phase 2, from 9:00 p.m. to 11:00 p.m the streetlights are dimmed to 40% (the brightness of a streetlight is decreased to 60%). With the continuation of phase 3, which starts from 11:00 p.m. till 5:00 a.m. the streetlights are dimmed to 60% (brightness is fixed at 40%). Succeeding to phase 4, from 5:00 a.m. till 6:00 a.m., the brightness of streetlights is increased to 60%. The data of the part-night lighting system is taken for one month (30 days).

### Smart Street Lighting System

In the contemporary world, saving electric energy is the primary concern for engineers, as power systems struggle to maintain an equilibrium between supply and demand. The continuous usage of streetlights leads to a huge waste of electric energy. Mainly, smart lighting system shows a path to combat these challenges; moreover, the integration of smart devices with streetlights could minimize the wastage of energy by up to 35% to 65%. The smart lighting system has advanced microcontrollers, which are set on the poles of streetlights. These smart embedded systems could perform; control luminaries, detect possible errors in the streetlights, and communicate helpful information. Further, lesser power consumption, low cost in the future outcome, and secured data transfer[9] are commonly used to create Wireless Sensor Networks (WSN). The motion sensor or passive infrared sensor(PIR) [28], these sensors will turn ON the lights upon detection of the vehicles or pedestrians; otherwise, it remains turned OFF[29]. Deep analysis of many sensors' technical and economic aspects is crucial for better accomplishment in the safety of people, cost-effectiveness, and electric utility. This project also includes a passive infrared sensor (PIR) sensor and global positioning system sensors (GPS) sensor to perform power consumption and cost analysis to present the benefits of a smart lighting system.

### Overview of Street Lighting Technologies

In modern street lighting, high-intensity discharge lamps, such HPS lamps, are widely employed. These lamps use the least amount of electricity while producing powerful photonic lighting. However, photonic and scotopic light analyses are typically used to demonstrate the inadequacies of HPS lamps when used for night lighting. Since the light sources triple drivers' peripheral vision and at least 25% prolong their braking response time, HPS lamp performance must be concentrated by at least 75% when employing light designs. A study found that a road illuminated with metal halide lighting was always brighter and safer at night than an identical area illuminated with HPS[2]. LEDs generate white light with higher scotopic brightness than older street lighting systems. They also generate less photonic light. An incandescent bulb only uses 10% of its energy to produce light; the other 90% is wasted as heat. Because they are easy to replace if damaged or stolen, they are typically used in places where there is a high risk of vandalism or theft; elsewhere, however, they are wasteful because LED systems, which use seven times less energy, can provide 5% energy efficiency and have lifespans of a few hundred hours, are more energy-efficient[14]. Additionally, after the light has been on for between 5 and 10 min, it must be struck again before it may be closed. They should not be used in environments where intelligent light control systems are in place [13]. MH (Metal Halide) lights typically last between 10,000 and 12,000 h. Another issue is the presence of lead and mercury in these lights. A 1500-W MH lamp has around 1 g of mercury in it. Despite having a CRI (color rendering index) of roughly 85, which is much higher, their use in municipal lighting has been limited by their short lifespan and high cost. Compact fluorescent lights (CFLs) have recently gained popularity because of their higher quality, but there is still space for development in dependability. Poor lumen output, high heat accumulation in the self-contained ballast, low life/burnout due to frequent light (on/off) cycling, and sources getting dimmer in cold conditions are some of the issues with CFLs. They include mercury but also have a respectable CRI of about 85 and a good CFL efficiency. Their light is a soft white with a color temperature of 3000 K. Additionally, they can produce colors with greater color temperatures [15]. The compassion of various lighting technology is shown in Table 1.

## IR Sensor Lighting System

The passive infrared sensor (PIR) is an electrical sensor used to measure heat emitted by living things or motion made by any item. It is highly effective when established on streetlights to power ON/OFF; moreover, when pedestrians or vehicles pass through, the sensor will pass on the information to the central supervisory system and enlighten the streets. Radiation emitted by the body can be detected by PIR sensors, as shown in Fig. 1 is one of the main components is a pyroelectric sensor which is extremely sensitive due to its ability to see weak infrared irradiation. If an object passes through the street, the IR radiation sensor is activated and acts accordingly as a given command. However, technological advancement poses some drawbacks, such that it is susceptible to various sources of heat that can be interfered with the device, causing a switch ON unnecessarily. As time proceeds, the PIR sensor's detection and sensitivity drop so that it might cause a short-time failure or behave abnormally.

## GPS Lighting System

GPS, a cutting-edge technique, is used to pinpoint a location precisely on Earth. Much research has been done on GPS technology to improve communication and data transfer between devices. In recent years, the GPS has emerged

**Table 1** Comparison of various street light technologies[5][15]

| Light technology | Ls/W | Coil temperature (k) | CRI | Inversion Time | Conditions |
|---|---|---|---|---|---|
| Incandescent light | 11.0–15.0 | 2.80 | 40.0 | Instant | Very ineffective, short lifespan |
| Mercury vapor light | 13.0–48.0 | 4.00 | 15.0–55.0 | ~15 min | Very inefficient and emits UV radiation that contains mercury |
| Metal halide light | 60.0–100.0 | 3.00–4.30 | 80.0 | ~15 min | High maintenance requirements, UV radiation that contains mercury and lead, and the potential to rupture when it expires |
| HPS light | 45.0–130.0 | 2.00 | 25.0 | ~15 min | It emits yellow light that contains mercury and lead and has a poor CRI |
| Low-pressure sodium light | 80.0–180.0 | 1.80 K | 0.0 | ~15 min | It emits yellow light with mercury and lead and has a low CRI |
| Fluorescent light | 60.0–100.0 | 2.70–6.20 | 70.0–90.0 | ~15 min | Effectively shatter glass and emits UV rays that comprise mercury |
| Solid fluorescent light | 50.0–72.0 | 2.70–6.20 | 85.0 | ~15 min | Low life, quickly overheat, and dimmer in cold temperatures |
| Induction light | 70.0–90.0 | 2.70–6.50 | 80.0 | Instant | The lead content, constrained directionality, and higher base cost are all detrimental effects of heat |
| LED light | 70.0–150.0 | 3.20–6.40 | 85.0–90.0 | Instant | The initial cost is relatively higher |

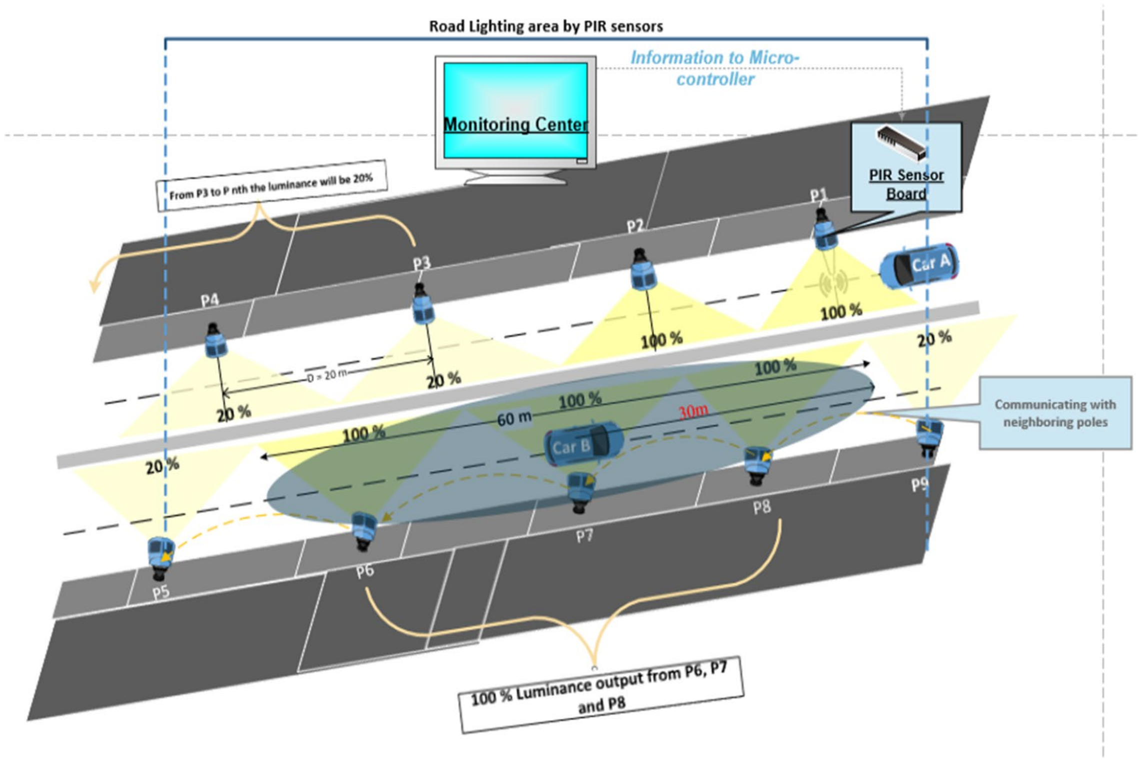


**Fig. 1** Segmented illumination area for Cars A and B in two separate scenarios, functioning under PIR-based streetlights

as an application in various fields like mobile phones for connectivity and ships to know the exact location on the sea. Besides, it could collect data on various traveling routes[30]. Mobile phones with integrated sensors and use-in-vehicle GPS sensors can send data to activate the traffic lights. The transfer of data and sensing of vehicles by microcontrollers are equipped on the streetlights for better accuracy. For instance, GPS sensors are used to operate streetlights automatically when wireless sensor network (WSN) technology collects data from passing passengers.

Furthermore, wireless sensor network (WSN) technology uses available data to personalize the luminaries on the streetlight. These collected data are transferred via radio waves to a central server for managing the data [31]. With this procedure, the streetlights trigger only themselves when there is a detection of a vehicle GPS or a mobile integrated GPS sensor else; they remain OFF when there are no such activities. Thus, GPS sensor lighting systems could increase optimization, cost-saving, and reduce the power consumption of streetlights. This method is reliable also beneficial in the future. However, it has some possible errors that eventually decrease GPS sensors' accuracy. The noise and distortion of electrical signals might cause interferences in GPS.

## Traffic Flow

Studies on different strategies are compared to approximate the volume of actual road traffic on the campus street. The case study of traffic data for seven consecutive days is collected to evaluate energy consumption and life cycle cost of different smart LED street lighting systems. According to traffic flow, street lights policy falls under a time-based or a situation-based division[32]. A situation-based traffic strategy is implemented as traffic volume or flow decides the street illumination. Although time-based adaptive strategies are implemented, the traffic volume is prerecorded, and light intensity is set accordingly. The traffic volume at different hours is recorded, starting from 6:00 p.m. till 6:00 a.m. depending upon the traffic volume shown in Table 1. illumination of the street is set. The paper presents test sites in the Aligarh Muslim University campus situated in west Uttar-Pradesh from the university triangle duck-point to Nawab Mohammad Ali Road, AMU campus. Around 100 vehicles and 150 pedestrians were detected at this site, considering their traveling speeds to be around 30 km/hr. and 5 km/hr. respectively.

## Myths of Using LED Lights

There are many misconceptions about what LED lighting is, how it operates, and its advantages regarding business LED lighting. Opinions are developed based on reality and fantasy, like any newly released product. Before making judgments about the requirements for commercial lighting, it is crucial to understand the reality of LED lighting. Here are some facts concerning LED lighting and some regrettable fallacies that persist.

i. Well, that depends on the viewpoint of the customer. Yes, LED may be a pricey investment if the initial cost is a concern. However, if long-term costs are considered, LED becomes significantly less expensive. Once the first installation is over, there will not be any bulbs that need to be purchased and changed because LED uses far less energy to illuminate the space.
ii. LED lights do not always last forever. Although 40,000–50,000 h are frequently claimed, it might be challenging to back up these claims. Unfortunately, some LED lights are of lesser quality, and the circuit boards that power them might fail. On the other hand, some LED lights have been available since the 1960s and are still functional today. The claims of excessive hour output will need to be evaluated, but numerous indications point to those numbers being accurate.
iii. Unlike CFL or fluorescent bulbs, LED lighting does not contain those products' hazardous mercury. The mercury in the bulbs seeps when they break, possibly contaminating the water supply. Not to mention the obvious advantages of using less energy, particularly in a significant business context. Without a doubt, LED is more environmentally friendly.
iv. LED illumination is currently available in a range of displays. LED lighting used to be constrained by the size and shape of the bulbs, but those days are long behind. With LED lighting, almost any presentation is now feasible. Given the versatility of LED lighting, businesses may create without hesitation.
v. Any business lighting requirement may be met with LED lights. There is no limit to what LED lights can do, from highly bright to candlelight brightness.
vi. Don't believe the tales that claim LED solely emits blue light. LED lights are available in various hues, including flawless white light. The days of LED constantly having a "hint of blue" are long gone.
vii. Some people think that exposure to LED light may be harmful due to reports that blue light might disrupt sleep. While it appears that difficulty falling asleep results from gazing at a TV, computer, or phone right before bed, LED light does not generate nearly as much blue light as those devices do. In actuality, the sun generates the bluest light, and lack of sleep is not associated with sun exposure

## Methodology

The HPS streetlights work under the conventional method of illuminating the streets and have luminance that doesn't alter. However, the LED street light operation is considered for the continuous period from 6:00 p.m to 6:00 a.m. Association with advanced technology and creative strategies are called upon to stimulate the process of conserving more energy. The part-night lighting system is one of the strategies for dimming the light intensity to alter the illumination of streetlights. Time manipulation in dimming the LED streetlight can be categorized into four-night phases. The observational was carried out on the campus streets of Street Aligarh Muslim University, UP. The Mohammad Ali Road of the AMU campus is taken for the case study. Figure 2 shows the lighting layout of the road. The streetlights are 20% dimmed from 6:00 p.m. till 9:00 p.m. in 1st phase, in 2nd phase the streetlights are 40% dimmed from 9:00 p.m. till 11:00 p.m. in the 3rd phase, the light is dimmed to 60% from 11:00 p.m. till 5:00 a.m., and in the 4th phase the light is dimmed to 40% from 5:00 a.m. till 6:00 a.m., and so on, the data of the part-night lighting system is taken for 1 month (30 days).

Thus, the study reveals that the part-night system is independent of traffic flow, and the energy consumption is constant throughout with variable traffic flow. Pursuing to minimize the utility of street lighting, the optimum path would be to increase a few luminous streets light and decrease the luminosity of other streetlights. Consequently, the proposed PIR sensor methodology qualifies the requirement for low energy consumption and maximizes efficiency. For the safety of individuals, the identification of suspects and the navigation of roads remain the primary main concern while designing methodology. Table 2 suggests the monthly power used during 30 days for part-night lighting set-up.

Moreover, for a random person to detect an object or to recognize another person, the sight distance is about 8–12 m. While looking at the vehicle's perspective, the availability of headlights in the car facilitates the driver to broaden the visuals at far distances. Therefore, setting up the illumination of streetlights at a constant level must be carried out for better visualization and protection from accidents. For the safety of the people, the vehicle's speed has been limited to 30 km/hr. by the authority on the campus. Based on the PIR street light model, the lighting of the road segment is 750 m, and further, it analyzes the utility of streetlights by altering the luminance progressively. From Fig. 3, the PIR sensor streetlights are patterned so that any passenger moving under a radius of 30 m would be illuminated at 100%.

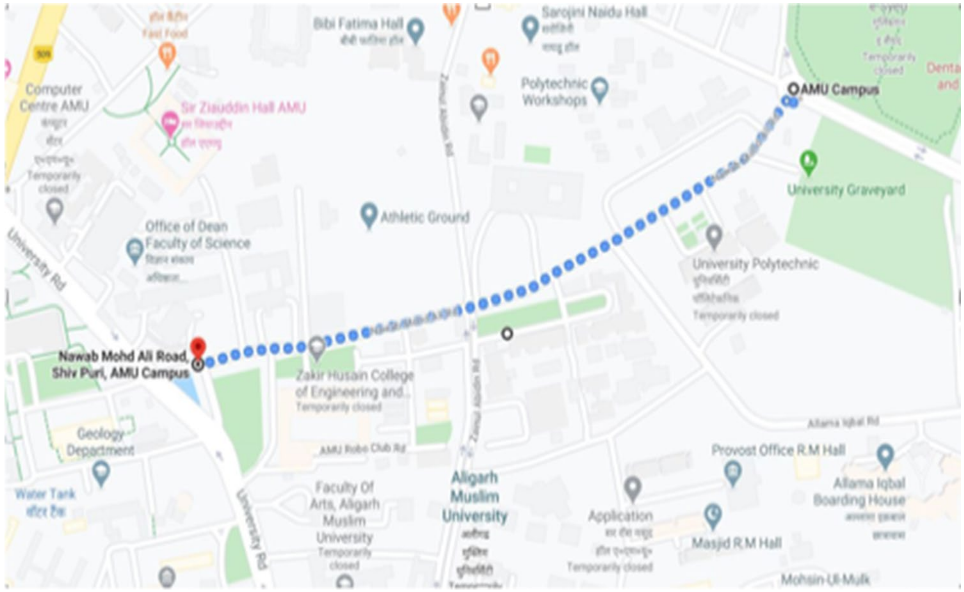


**Fig. 2** Nawab Mohamad Ali road of AMU, Aligarh

**Table 2** Power usage for a month using a part-night lighting setup

| Hours (hr.) | Illumination (%) | Dimming (%) | Total power con sumption (kWh) | Monthly power consumption (kWh) |
|---|---|---|---|---|
| 6–9 p.m | 80 | 20 | 8.64 | 259.2 |
| 9–11 p.m | 60 | 40 | 4.32 | 129.6 |
| 11–5 p.m | 40 | 60 | 8.64 | 259.2 |
| 5–6 p.m | 60 | 40 | 2.16 | 64.8 |

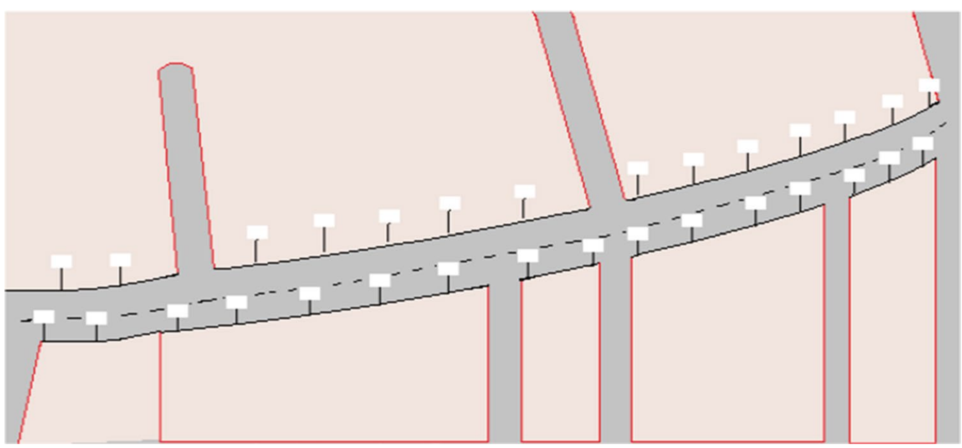

**Fig. 3** streetlights spread out across a 750 m region on a campus

The illumination of each streetlight has been programmed to be 20% when there is no detection of objects.

Ultimately it improves efficiency and minimizes the consumption of electricity. The total utility mathematical modeling can be represented by Eqs. (1)–(3). As the passenger's distance increase from 30 m from the P1, the sensor is automated and reduces the illumination to 20%. The sensing pole sensors the passenger with corresponding streetlights. The illumination increases to 100%, as the distance from the sensing pole, which is P3, pole P1 reduces its illumination to 20%. Since pedestrian speed is about 5 km/hr. (1.38 m/s), the time taken to reach from one pole to another is 15 s. In the equation, $d_{avg}$ and $d'_{avg}$ is the average distance covered by the pedestrian and vehicle, respectively; the total utility of illumination in the area can be calculated by considering the variable speed. Finally, μ is the time consumed by the vehicles and pedestrians here, μ is valued to be μ = 1.

$$\text{L total Utility } = [\mu\text{L moving pedestrian } (d_{avg}, U_{avg})\text{ t} + \mu\text{L}' \text{ moving vehicle } (d'_{avg}, U'_{avg})\text{ t}] \quad (1)$$

$$\begin{bmatrix} \text{L Pedestrian Utility} \\ \text{L Vehicle Utility} \end{bmatrix} = \begin{bmatrix} \text{t moving} & \text{t}' \text{ moving} \\ \text{t stopping} & \text{t}' \text{ stopping} \end{bmatrix} \begin{bmatrix} \text{U pedestrian} \\ \text{U vehicle} \end{bmatrix} \quad (2)$$

$$\text{Psensor} = \begin{cases} 100\%, dradius \le 30 \\ 20\%, dradius > 30 \end{cases} \quad (3)$$

The proposed model works under a wireless multi-sensor network (WMSN), and each streetlight has its IP address to facilitate communication with neighboring streetlights to exchange information [22].

The illuminance of each streetlight is timely and synchronized according to the passenger's location. Besides, it is pre-programmed for better instant response to adjust its luminance. Furthermore, its significant energy saving is discussed in the Result section. The illumination of streetlights is programmed so that on the detection site, the streetlight operates with 100% luminance, while the rest of the streetlights operate at 20%. This operation optimized street lights and positively affected operating life, low power consumption, and less electricity[14]. Moreover, causing less pollution of $CO_2$ at a larger scale and less light pollution can be experienced.

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Similarly, GPS sensors can also be implemented in this methodology that enables data transfer for better connectivity. Accountability of vehicles and passenger data will benefit streetlights for optimizing luminous efficacy. Moreover, microcontrollers are equipped on the streetlamp poles to transfer data and sense of vehicles for better accuracy. Here the GPS sensors are used to operate streetlights automatically when the sensors collect data from passengers.

This can be achieved by wireless sensor network (WSN) technology, which can control the streetlight's light intensity and transfer collected data via radio wave to the central server for managing the data. Thus, GPS sensors can also be implemented with the proposed methodology, and their power consumption and cost analysis are discussed in the forthcoming sections. Figure 4 shows the street light design made using GPS based approach.

## Results and Discussion

The estimation of power consumption by LED lamps, part-night lamps, solar-powered lamps, and smart lighting systems is considered for six months. The energy usage by the 36 LED lamps for one month is calculated to be 1,296 kWh in the university triangle duck-point to 'Nawab Mohammad Ali' road, AMU campus.

### Power Consumption Analysis

The part-night lighting system is presented to analyze energy consumption and cost-effectiveness. The comparison of energy-saving with different smart LED systems comprises time-based and conventional systems projected in Figs. 5 and 6 for 1 month and six months, respectively.

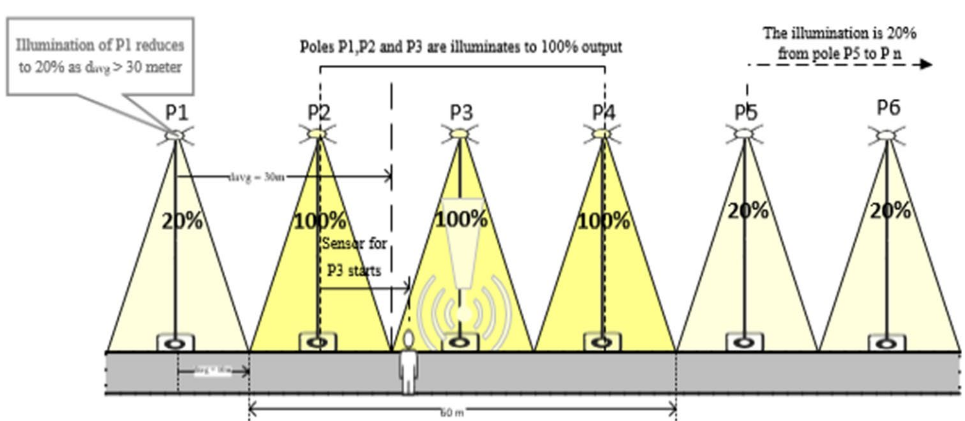


**Fig. 4** The street lighting design using GPS approach[32]

It shows that the smart lighting system saves around 96.2% of the energy compared to conventional time-based LED systems, and the part-night system saves energy by 45% of the conventional lighting system.

Analysis of energy consumption shows that part-night lighting schemes consume 712.8 kWh, which is 55% of the total consumption in a conventional lighting system. Similarly, compared to PIR and GPS sensors, the power consumption is 1.633 kWh which is 3.8% of the total LED system consumption in the conventional time-based system. Hence, the energy and economic analysis from Fig. 6 and 7 shows the road's traffic flow. Figure 8 shows that the smart LED lighting system is highly effective against part-night and conventional lighting systems. The energy utility of can be calculated by Eq. (4).

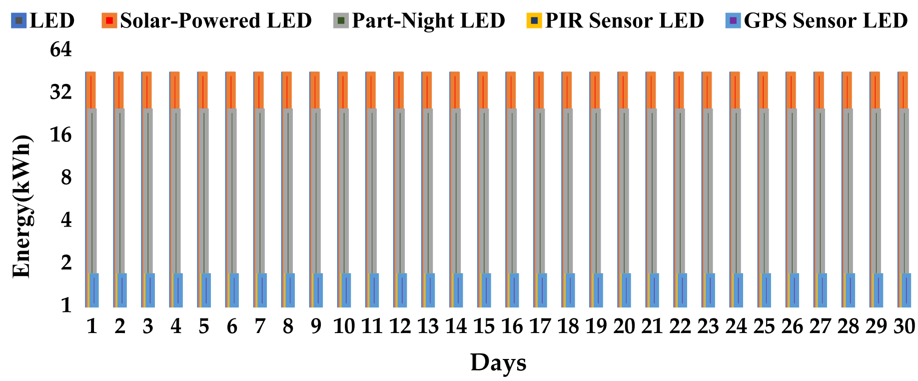


**Fig. 5** Usage of energy by different lighting strategies for one month

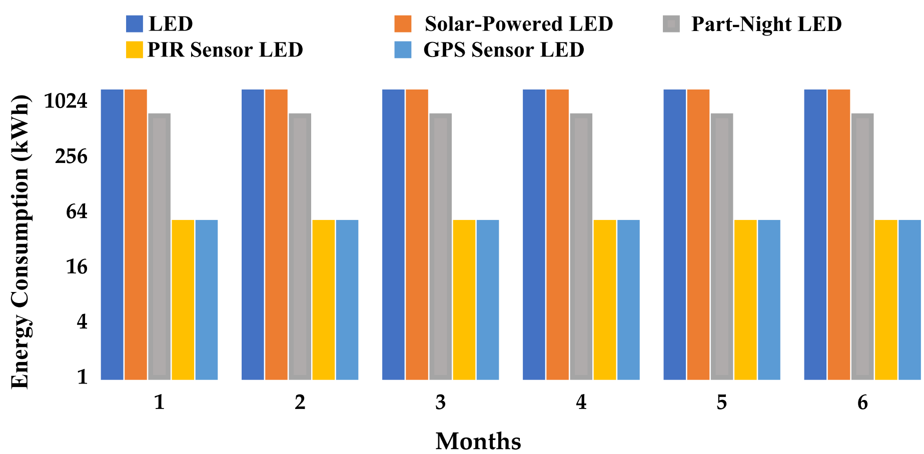


**Fig. 6** Usage of energy by different lighting strategies for six months

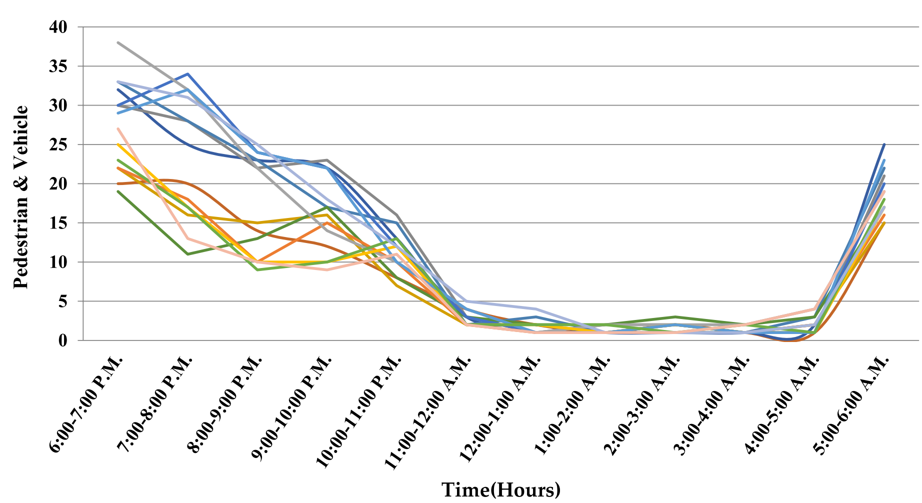


**Fig. 7** Traffic flow for each hour starting from 6:00 p.m. till 6:00 a.m

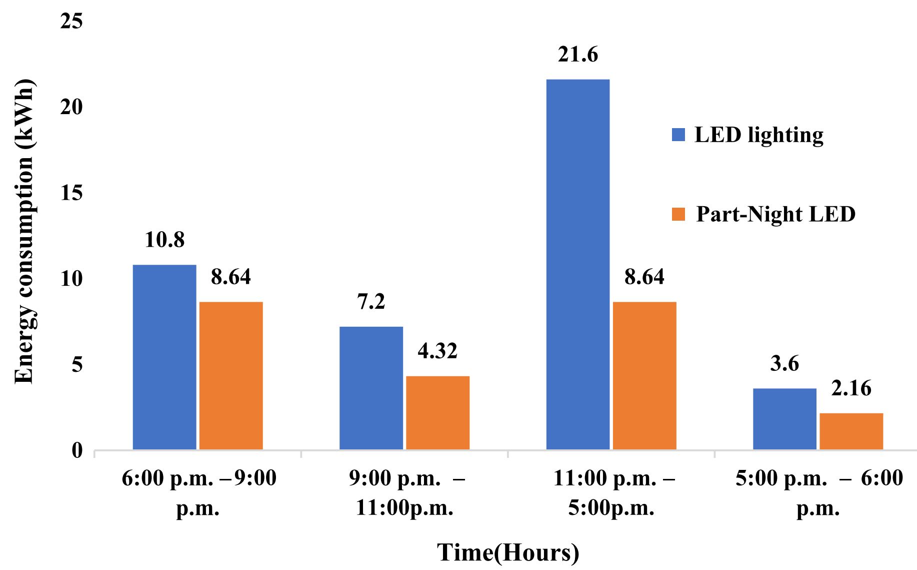


**Fig. 8** Power consumption analysis on base LED and part-night system at different hours

$$E_{\text{utility}} = \sum_{k=1}^{n} \left( \frac{W}{1000}^{n.} .T^{n} \right) \kappa \quad (4)$$

where k is the energy factor of a given bulb type, here, we have considered energy factor k = 1, where n is the number of streetlights in usage.

### Part-Night Power Consumption Cost Analysis

The different operating period and the variation in the brightness of streetlights result in additional power consumption. The power consumption data for one night is calculated, and for one month is shown in Table 1. The brightness of a streetlight is maximized from 6:00 p.m. till 9:00 p.m. (80% brightness), and the total power consumed for 3 h is 8.64 kWh. Following the next 2 h, the brightness was set at 60%, resulting in a power consumption of 4.32 kWh. Subsequently, for the next six hours, the brightness of the streetlight was set at 40%, which resulted in total power consumption of 8.64 kWh. Finally, from. 5:00 a.m. to 6:00 a.m. the brightness was increased to 60% consuming 2.16 kWh. In Fig. 8 the comparison between LED conventional lighting system and part-night LED system.

However, the part-night lighting operation has some limitations, such that it mainly depends on location, population-based area [26], and the availability of economic sources. Although these strategies have reduced nearly 34 to 49% of carbon emissions, that ultimately benefits the authority to save energy. The case study of seven days of week traffic data has been gathered to evaluate energy consumption and life cycle cost of different smart LED-based streetlight systems. Due to their increased color output, elimination of dark spaces between poles, and equal lighting distribution, LED streetlights are superior to HID streetlights in the following ways. Reduced upward light reflection, one of the primary sources of urban sky glow, assures between 40 and 80 percent energy efficiency, subject to the required criteria and the lighting source. reduces the cost of maintenance for smart LEDs by 50–75%. However, LED has two main disadvantages. The first is the price of an LED streetlamp, which requires a sizable initial capital outlay due to its 2–8 times higher price than a standard HID bulb. The rapid advancement of LED-based illumination and the associated knowledge opened new possibilities for designing and managing public lighting systems. Since each device is built with a unique set of tools and materials, they each work for a different time. The usage of a digital illuminance meter during daytime operations served as a demonstration of this.

### Cost Review

With the urbanization of the community and the search for sustainable life, people are shifting toward smart technologies. These technologies enhance security and have a broad scope of energy saving[33]. The cost analysis of the suggested model is discussed in the subsequent section.

#### *Power Consumption Cost Analysis*

The energy cost is increasing at a higher rate, so economic analysis for different street lighting systems is necessary. In Fig. 9, the cost analysis is shown for various street lighting schemes and compares them based on their power consumption. The investigation will be carried out for 6 months, from November 2020 to April 2021. UPERC (Uttar Pradesh Electricity Regulatory Commission) states that the unit (kWh) energy is charged for about 0.080 $/kWh. Figure 9 presents the energy cost analysis of different lighting schemes.

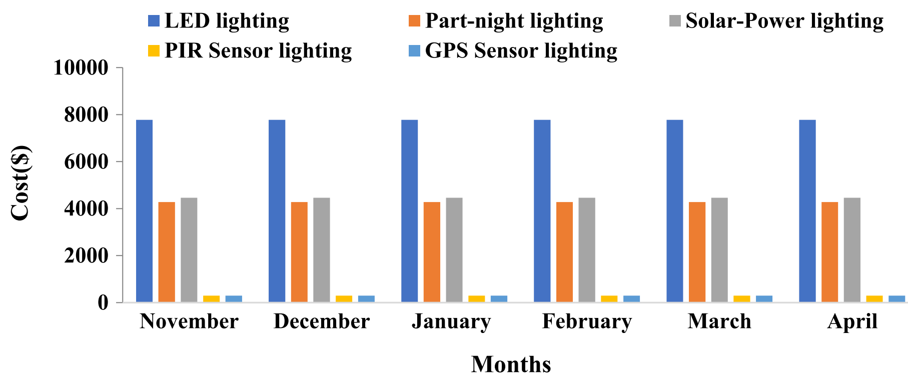


**Fig. 9** Present value energy cost of different street lights schemes during 2020–2021

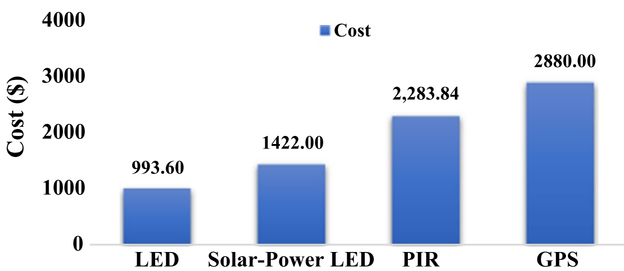


**Fig. 10** Installation cost of different street lights schemes

The energy consumption under the conventional timing LED lamps is estimated to be 104.02$/m. For instance, part-night lighting systems are compared to analyze the energy-saving and cost of electricity for the same duration of time, which cost $57.21/m, which renders a better economic saving than the conventional system. Moreover, the power consumption cost of the solar-powered LED lighting system is estimated to be $59.64/m, which is lesser than the traditional timing system. However, compared to a part-night lighting system, it shows higher energy consumption. In Fig. 9, considering smart lighting systems over part-night lighting and solar-powered LED lighting systems, energy consumption significantly reduces. Smart technology could lumen the streets when there is a requirement, which causes lower electricity consumption though the cost of electricity is valued to be $3.93/m. Furthermore, this results in a total cost saving of 96.13% and 93.12% compared to solar-powered LED lighting systems and part-night lighting schemes, respectively. This clearly shows the improvement in the result of using smart lighting schemes.

*Installation Cost*

The approach toward reduction in cost consumption and maximizing energy conservation has been prioritized. In Fig. 10, the data collected for different lighting systems will conserve time at the more significant projects to select suitable lighting systems upon installation of streetlights. Here, comparing other lighting systems is tested upon 36 lamps of 100 watts considered for better understanding.

LED light lamp with a maximum lumen of 130 lm/W, the installation cost for 36 streetlamps is estimated to be $993.60. Furthermore, the solar-power LED lamp for less power consumption has a luminous flux of 3000, estimated at $1422.00. Subsequently, the smart LED lighting system consisting of PIR sensors and GPS sensors lighting system has been estimated at $2283.84 and $2880.00, respectively. Although the installation cost is relatively high for PIR and GPS sensors compared to other LED lighting systems, the payback time will be within 5–6 years from installation.

*$CO_2$ Emission*

Global warming is a worldwide disaster intentionally being ignored by a large population, and we must protect our environment from harmful elements[34]. In India, thermal power plants consume 70% of the total coal, making it the largest energy source for electricity[35]. For instance, the electricity demands each year have increased, consuming more non-renewable energy sources and releasing large amounts of $CO_2$ into the atmosphere. Electricity generation is responsible for 42.5% of global $CO_2$ emissions. Coal power plants, which provide electricity while generating 950 g of $CO_2$ per kilowatt-hour as opposed to 350 grams for gas-fired power plants, may be responsible for 73% of this[36]. In contrast to the generation of $CO_2$ from coal or natural gas, electricity produces $10^6$ tons of carbon. From the section power consumption analysis, the energy consumption of different lighting systems has been calculated for six months.

Further, it shows that carbon dioxide emission by different lighting systems results in operating hours. In Table 2, the $CO_2$ emission is calculated for one month period for better understanding. The conventional lighting system consumes high energy, which causes a huge amount of $CO_2$ emission that is 6,998.4□ kg of $CO_2$. Focusing on the part-night lighting system emits 3,849.12□ kg of $CO_2$, whereas the solar-powered lighting system that has a solar power supply as an option emits 4,012.416□ kg of $CO_2$, which

**Table 3** $CO_2$ emission of different lighting systems

| Type of lighting system | $CO_2$ emission (kg/kWh/yr.) |
|---|---|
| LED conventional timing | 583.2 |
| Part-night | 320.76 |
| Solar-powered | 334.368 |
| Smart lighting system | 22.047 |

**Table 4** shows the average rated life of the different bulb

| Bulb type | Avg. lifetime | Lumen/Watt |
|---|---|---|
| Incandescent | 750–2,000 h | 12–18 |
| HPS | 20,000–24,000 h | 80–140 |
| LED | 40,000–50,000 h | 30–90 |
| Halogen | 2,000–4,000 h | Oct-20 |

is greater than the part-night lighting system. Finally, a smart LED lighting system that benefits energy saving at a larger scale also contributes to the reduced $CO_2$ emissions, accounting for 264.564 kg of $CO_2$. Thus, the proposed method of lowering the brightness with the smart lighting system could save the environment from the increasing level of $CO_2$ in the atmosphere. Therefore, lowering the illumination of streetlights could reduce energy generation from power plants and save thousands of dollars per kWh of electricity each year. Table 3 suggests the $CO_2$ emission by different lighting systems. Most streetlamps are made of sodium vapor, mainly divided into high-pressure sodium (HPS) and low-pressure sodium (LPS). High-pressure sodium is used more because it has higher luminous efficiency, consumes less power, and lasts longer. And its fog permeability is also excellent, making it safer to travel at night and reducing the probability of traffic accidents[37]. But the high-pressure sodium lamp also has the disadvantage of poor color rendering. It appears white when first opened and turns yellow after a while; no matter what the object is, it is yellow. For road lighting, color rendering is not that important. In driving at night, you only need to see the size and shape of the oncoming car, not the car's color. Simply, the streetlight is yellow or orange because it uses high-pressure sodium light. First, Table 4 shows different bulbs' average rated life and lumens per watt. The HPS has about seven times more lumens per watt than incandescent bulbs and can last up to 24,000 h. Therefore, the sodium light is bright enough and has a long service life. Another important reason is that it consumes less power. Because it only produces light visible to the human eyes. Incandescent lamps produce light in all frequency ranges from infrared to ultraviolet, which is very power-hungry. Therefore, sodium lamps have apparent advantages in terms of cost and efficiency compared to other light bulbs, so why not use sodium lamps? Since the 1980s, HPS lamps have been widely used in streetlights, and people have gradually become accustomed to yellow streetlights. Initiatives for public lighting are being put into place in many places throughout the world for two main reasons: neighborhood safety and economic development. Public lighting encourages economic growth by extending people's opportunities for dining and entertainment after dark. According to studies, public lighting can reduce crime by up to 20% and traffic accidents by up to 35%.

LED lighting is advantageous to the environment and local government finances. Compared to traditional lighting, LED technology is between 40 and 60% more energy efficient. By simply installing LED lights, better lighting may be given while using less energy and emitting fewer $CO_2$ emissions. By switching to LED outdoor lighting, the United States alone could save USD 6 billion annually and reduce carbon emissions by taking 8.5 million cars off the road for a year. Operations and maintenance (O&M) costs for LED luminaires typically fall significantly because they have a lifespan of at least four times longer than conventional bulbs. The cost reductions may make it simpler for municipalities with limited financial resources and high utility expenditures to manage their finances. For instance, in Quezon City, Philippines, street lighting costs comprised 5% of the city's overall budget and 65% of its electrical expenditures. In India, the electricity and upkeep for street lighting can take up 5 to 10% of municipal budgets in large cities and up to 20% in smaller cities. Cities that invest in LED street lighting can utilize the savings to pay for other municipal services, such as sanitation, public health, or education. However, many municipal cities cannot capitalize on this "low-hanging fruit due to institutional and financial constraints." The energy and cost savings potential of LED public lighting far outweigh the initial investment, and physical retrofitting is not particularly challenging, although the capital costs are still higher than those of conventional systems. Unsubsidized LED luminaires may cost twice as much as high-pressure sodium vapor (HPS), depending on taxes, exchange rates, the presence or absence of local manufacture, and the breadth of the LED program. Capital investments may be prohibitively expensive for local governments with inadequate funding. Many local governments in developing countries lack the credit needed to obtain money on the market, or the cost would be so high that the profitability of the lighting program would be considerably affected. Cities may also experience problems with perceptions, an unfavorable regulatory environment, and a lack of institutional capacity to develop and operate complicated business models.

## Conclusion

This paper discussed various methods of implementing the smart street lighting system and a proposed method for PIR smart street lighting. This research also analyzes the installation and running costs (six-month period) for better assessment in future projects. This approach is useful in decision-making for larger projects as it describes the suitable methodology for smart lighting systems and discusses operational collected data. The installation of a smart LED lighting system on the streets dynamically changes the illumination of streetlights, ultimately minimizing energy consumption and benefits in payback time. The proposed system is also adaptable to GPS sensor lighting systems, the same as the PIR lighting system design structure. For the present scenario, the PIR lighting system can achieve an energy saving of 84% compared to conventional LED lighting. The installation cost of PIR and GPS sensor lighting systems and other lighting systems are compared. Moreover, the smart street lighting system will improve energy saving, lowers the emission of $CO_2$, and brings easement in installing smart sensors on streetlights in the larger domain. The study contributes to the power consumption and costs analysis projects struggling to reduce energy consumption and further observes budget constraints upon installation.

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**Data Availability** The current study does not use any scientific datasets. The present paper's information, facts, and figures are duly cited and appropriately added to the references.

**Declarations**

**Conflict of interest** The authors declare that they have no known conflict of interest.

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