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A LoRa Based IoT Framework for Real-Time Lux Monitoring and Energy Efficient Lighting Management

Ranjana Ubale[1], Kailash Sapnar[2]

[1]Department of Electronic Science, Fergusson College, Pune, India
Email: *rsubale369[at]gmail.com*

[2]Department of Physics, Fergusson College, Pune, India

Abstract: ***Recent advances in Internet of Things (IoT) technologies, low-power wireless communication, and embedded electronics have created practical opportunities for continuous illumination monitoring in energy conscious buildings. This study presents a LoRa based IoT framework for distributed, real time lux sensing and energy efficient lighting management. The framework combines BH1750 digital light sensors, an ESP8266 microcontroller, SX1278 LoRa transceivers, and a gateway connected monitoring interface to acquire and transmit indoor illuminance data. The experimental evaluation was conducted in an office room with an area of approximately 9.01 m² using two Philips LED luminaires with a DIALux input power of 36W per luminaire and a target illuminance of 200 lux. The DIALux model was compared with hardware measurements under artificial light only and daylight assisted conditions. The BH1750 sensing unit was validated against a standard lux meter, with an average measurement error of approximately 3.18%. During the office test, illuminance was monitored from 10:00AM to 5:00PM, and observation points were used for simulation to measurement comparison. The temporal profiles showed a strong positive correlation between simulated and measured illuminance. The LoRa link operated at 433MHz with a 10-second application layer transmission interval, and no packet loss was observed during the logged test run. The results demonstrate that real time lux monitoring can reveal daylight availability and provide a practical data layer for daylight responsive lighting management. The study focuses on the demonstrated monitoring capability; automatic closed loop dimming and relay control are identified as future extensions.***

Keywords: Internet of Things, LoRa, Lux Sensing, Illuminance Monitoring, Smart Lighting, Energy Efficiency

1. Introduction

Lighting is an important operational requirement in offices, workshops, laboratories, warehouses, and industrial facilities because adequate illuminance directly affects task visibility, safety, and visual comfort. Conventional installations often operate at fixed output levels and therefore do not respond to changes in daylight availability. This operating practice can increase artificial lighting use during periods when natural light already provides a substantial part of the required illuminance.

The integration of IoT sensing with lighting infrastructure provides a way to observe illumination conditions continuously and to make the resulting data available for analysis and future control. IoT architectures typically combine sensing, embedded processing, communication, and application-layer monitoring, allowing distributed measurements to be collected without extensive wired instrumentation [1]. For large or spatially distributed installations, low-power wide-area communication is attractive because it can provide long-range connectivity with comparatively low communication overhead [2], [3].

Daylight is particularly important in energy-efficient lighting management because indoor illuminance varies with solar position, sky condition, window geometry, orientation, and interior surface characteristics. Previous research has shown that daylight-responsive systems can reduce artificial-lighting demand while maintaining useful work-plane illumination [4], [5]. The effectiveness of daylight utilization also depends on building orientation and window-to-wall ratio, which influence the amount and distribution of natural light entering a space [6].

The present work therefore concentrates on the development and experimental evaluation of a LoRa-based lux-monitoring framework. The objective is not to claim a fully validated automatic lighting-control system, but to establish a reliable sensing and communication layer that can support energy-efficient lighting management. The study combines DIALux simulation with real measurements so that the temporal behaviour of indoor illuminance can be examined under practical daylight conditions.

2. Literature Review

IoT-based environmental monitoring has developed from isolated sensing devices toward interconnected systems capable of remote data acquisition, storage, and visualization [1]. In lighting applications, this architecture can be used to measure illuminance and identify periods of over-illumination or insufficient daylight. Smart-lighting research increasingly combines efficient LED sources with sensing and control functions, moving lighting infrastructure toward connected and data-driven operation [4].

Wireless communication is a major design consideration for distributed lighting sensors. Wi-Fi provides high throughput and straightforward Internet connectivity but depends on local network infrastructure. LPWAN technologies, including LoRaWAN, are designed for long-range communication with low data rates and low energy requirements. Adelantado et al. discussed the practical limits of LoRaWAN and showed that its performance depends strongly on application requirements and radio configuration [2]. Sanchez Iborra and Cano similarly reviewed LPWAN technologies for industrial IoT services and highlighted the suitability of low-power long-range communication for distributed monitoring [3].

Daylight utilization provides an additional pathway for reducing unnecessary artificial lighting operation. Modern lighting research considers daylight contribution, electric-lighting demand, and occupant requirements together rather than treating artificial lighting as an independent load [5]. Building orientation, window-to-wall ratio, and shading conditions also affect daylight availability and therefore influence the achievable energy-saving potential [6]. These findings support the use of real-time illuminance sensing as a measurement layer for daylight responsive lighting management.

Despite substantial progress in smart lighting, there remains practical value in low-cost frameworks that connect indoor lux measurements with simulation results and long-range wireless monitoring. The contribution of this work is the integration of digital lux sensing, embedded processing, LoRa transmission, and DIALux based comparison in a compact experimental framework. The resulting system provides measured illumination data that can subsequently be used for adaptive lighting strategies.

3. Experimental Setup

3.1 Experimental Environment and DIALux Model

The experimental study was conducted in a real office room with an area of approximately 97 sq. ft. (9.01m²). The room was modelled in DIALux using its measured geometry, luminaire arrangement, working-plane configuration, and daylight opening. The design target was 200lux for the office workspace. A maintenance factor of 0.80 and a uniformity target of 0.50 were used in the simulation. The DIALux model was evaluated for artificial light only and daylight assisted conditions.

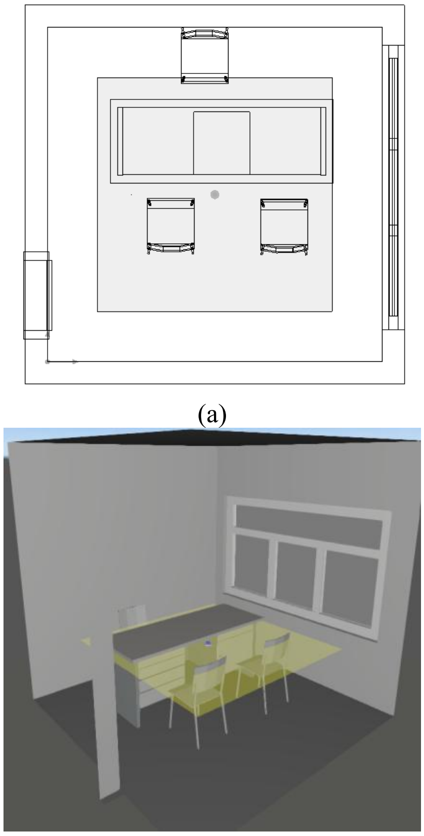
Three Philips round LED luminaires were used in the lighting model. The product designation was a 42W Philips 3000K round luminaire; the DIALux input power was 36W per luminaire, with a luminous flux of 4199lm and a calculated luminous efficacy of 116.6lm/W. These values were retained from the original experimental manuscript.

Table1: Luminaire specification used in the DIALux model

Pcs	Manufacturer	Article Name	P	Φ	Luminous Efficacy
2	Philips	42W Philips (3000K) Round	36.0W	4199lm	116.6lm/W

The DIALux simulation settings included a uniformity factor of 0.5, a maintenance factor (MF) of 0.80, and appropriate geographical orientation parameters such as latitude, longitude, north alignment, and XYZ coordinate settings. According to EN 12464-1 (Indoor Workplace Lighting Standard), the recommended illuminance level for the office cabin was 200lux. The lighting design was optimized to achieve this target illuminance. Subsequently, various performance parameters were calculated and analyzed, including energy consumption, luminous intensity, energy savings achieved by LED lighting, luminaire luminous efficiency, and color rendering index (CRI).

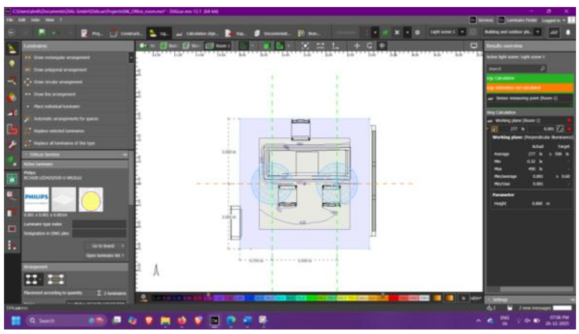
Figure 1 illustrates the room layout, lighting parameters, and the 2D and 3D views of the modeled office room used in the study. Figure. 1 shows the 2D and 3D DIALux models representing the office room layout, including the workstations, window, room geometry, and lighting arrangement. Figure 2 shows the luminaire positions and the defined illuminance measurement area on the working plane. The lighting distribution and measurement points are used to evaluate the illuminance performance of the office room. These figures demonstrate the DIALux modelling and measurement setup used to analyze lighting performance and illuminance distribution.



(a)

(b)

Figure 1: Office room model used in DIALux: (a) 2D layout and (b) 3D representation.



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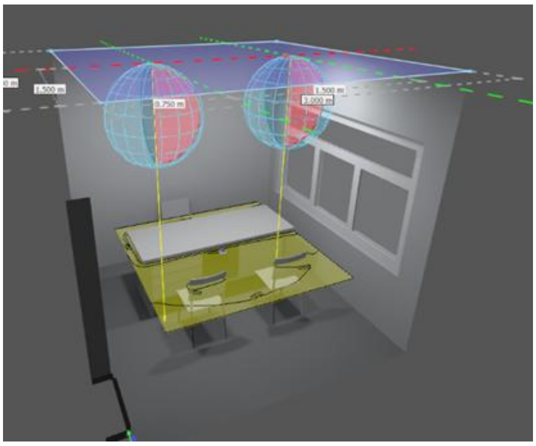

(b)

Figure 2: Luminaire arrangement and illuminance measurement region in the DIALux model.

3.2 Lux Sensing and Wireless Monitoring Hardware

The final sensing architecture used a BH1750 digital ambient light sensor interfaced to an ESP8266 microcontroller through the I²C interface. The BH1750 was selected because it provides a direct digital illuminance output and is suitable for low-complexity continuous measurement [7]. The sensing unit was connected to an SX1278 LoRa transceiver for long range wireless transmission. A receiver/gateway collected the transmitted lux data and made the measurements available to the monitoring interface.

The LoRa radio was operated in the 433MHz band. The application layer lux packet transmission interval in the prototype firmware was 10s. The experimental record did not document an independent spreading factor, bandwidth, or coding-rate sweep; therefore, no unverified values for those parameters are reported here. This avoids attributing performance to radio settings that were not systematically measured.

The measurement system was calibrated by comparing BH1750 readings with a standard calibrated lux meter under controlled indoor lighting. The comparison procedure used the absolute percentage error for each observation, calculated as $|L\_BH1750 - L\_ref|/L\_ref \times 100|$, followed by averaging over the validation observations. The resulting average error was approximately 3.18%, indicating adequate agreement for the intended monitoring application. The development of the proposed IoT-based lux sensing and monitoring framework follows a systematic and modular methodology. Careful selection of hardware components, communication technology, and software tools ensures accurate illumination measurement, long range data transmission, and reliable system performance. The overall system is divided into independent subsystems: sensing, processing, communication, and cloud monitoring, which are developed separately and later integrated into a complete functional solution. High precision digital light sensors such as BH1750 and TSL2561 are used for lux measurement due to their stable output, low noise characteristics, and I²C communication interface. These sensors can measure illumination over a wide dynamic range, enabling effective operation under both low light and high intensity lighting conditions.

The microcontroller is selected for sensor data processing and device control because of its compact size, low power consumption, and strong compatibility with IoT platforms. To achieve long range and low power wireless communication, the microcontroller is interfaced with a LoRa transceiver. LoRa modulation significantly reduces power consumption while ensuring reliable data transmission over extended distances, even in outdoor or partially obstructed industrial environments. Each sensor node is powered using either a USB supply or a battery source, depending on deployment requirements. Components are assembled on a compact PCB or prototype board to ensure ease of installation and long-term reliability in field conditions.

This integrated approach ensures that the system remains scalable, energy efficient, and suitable for diverse applications such as smart city lighting, industrial workspace monitoring, and precision agriculture illumination analysis. The proposed energy efficient lighting control system follows a modular IoT architecture consisting of: Sensing Unit, Processing and Communication Unit, Gateway and Cloud Interface, and Visualization and Decision Support Layer. Each subsystem is independently designed and integrated to ensure scalability and reliability. Ambient illumination is measured using the BH1750 digital lux sensor, which offers high accuracy, wide dynamic range, direct lux output, and low noise performance. The sensor communicates with the microcontroller via the I²C interface, ensuring precise and stable data acquisition suitable for industrial lighting assessment. The microcontroller processes sensor data and manages communication tasks due to its low power consumption and strong IoT ecosystem support. For long-range wireless transmission, the microcontroller is interfaced with a LoRa transceiver. LoRa enables reliable data transmission across large industrial areas while maintaining low energy consumption and minimal packet loss. A centralized LoRa gateway receives lux data from multiple sensor nodes and forwards it to a cloud server using Wi-Fi or Ethernet. Cloud platforms such as ThingSpeak or Firebase are used to store historical data, display real-time dashboards, and support trend analysis and anomaly detection. The system is calibrated using a standard handheld lux meter. Measurements are recorded at regular intervals throughout the day to evaluate system accuracy, reliability, and response under varying daylight conditions.

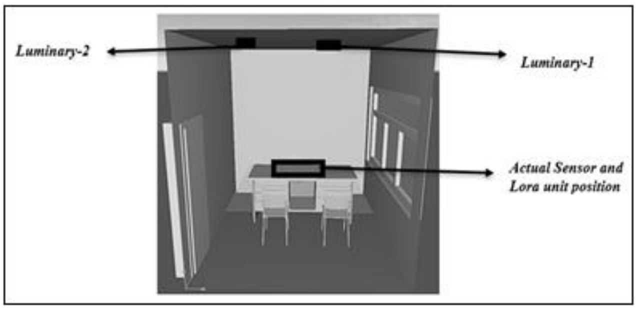

Figure 3: Actual office room arrangement showing luminaire and LoRa-based sensing unit positions.

Figure 3 shows the actual office room arrangement showing luminaire and LoRa based sensing-unit positions. of Luminaire-1, Luminaire-2, and the installed sensor with LoRa unit. It illustrates the practical placement of lighting fixtures and the sensing hardware used for real-time illuminance monitoring.

3.3 Measurement Procedure and Evaluation Metrics

Real-time measurements were collected during office operation from 10:00AM to 5:00PM. For the comparative time series analysis, half-hourly observation points were used. The hardware system continued sensing and transmitting at the configured 30-minute interval, while the values were used as the common comparison points for the DIALux and measured datasets. Artificial light and daylight assisted conditions were considered.

4. Result and Discussion

Experimental results validate the effectiveness of the proposed IoT-based lux sensing and monitoring framework. The light sensor, interfaced with the microcontroller, successfully captured real time illumination data, which was transmitted via the LoRa module to the gateway and displayed on the web server. To evaluate measurement accuracy, lux values recorded on the cloud dashboard were compared with readings obtained from a standard lux meter at different time intervals between 10:00AM and 05:00PM. The results show a strong correlation between system readings and reference values. Minimal error was observed during stable lighting conditions, while slightly higher deviations occurred during peak daylight hours due to rapid environmental light variations and sensor response characteristics.

The LoRa based communication demonstrated stable long-range performance with consistent data delivery and no significant packet loss throughout the test duration. This confirms the suitability of the system for large industrial environments were conventional wireless technologies face coverage and reliability limitations. Continuous lux monitoring enables effective daylight harvesting, zone-wise lighting control, and intelligent dimming, directly contributing to reduced energy consumption, improved lighting quality, and compliance with industrial illumination standards.

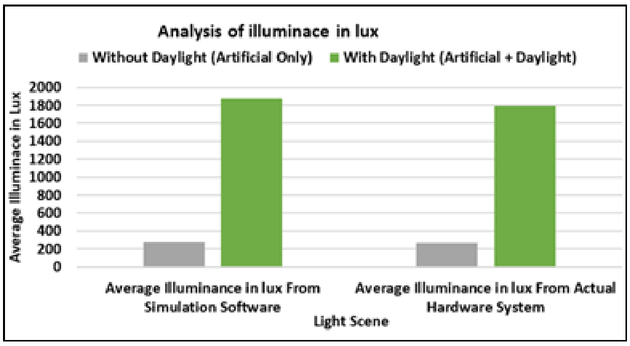

Figure 4: Comparison of average illuminance under artificial light and daylight assisted conditions.

Figure 4 shows that, in the absence of daylight, the lighting system consisting of three 36Watt LED luminaires successfully achieved the target illuminance level of 200lux, as observed in both the lighting simulation results and the actual hardware measurements. The close agreement between simulated and measured illuminance values confirms that the lighting design is adequate for providing the required visual comfort using artificial lighting alone. When daylight was introduced, a significant increase in average illuminance was observed in both the simulation and hardware measurement results.

The illuminance levels exceeded the target lux value, indicating a strong contribution from natural daylight. The simulation results show slightly higher illuminance compared to the hardware measurements, which can be attributed to real world factors such as sky condition variations, shading, and sensor placement.

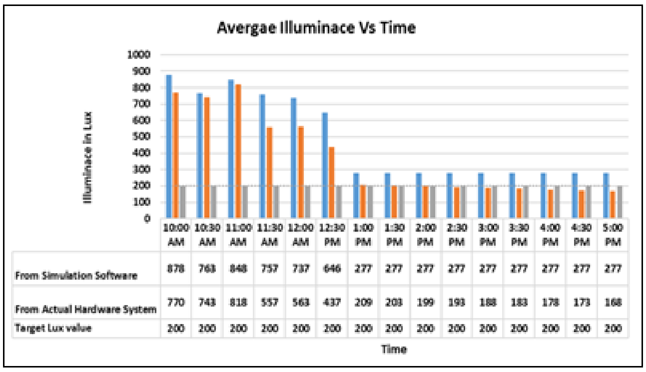

Figure 5: Simulated and measured illuminance at 30-minute intervals from 10:00AM to 5:00PM.

Figure 5 shows the variation of average indoor illuminance (lux) with time from 10:00AM to 5:00PM for an office space. The results compare simulation data (DIALux), actual hardware sensor measurements, and the target illuminance level of 200lux recommended for office environments. During morning hours, both simulation and hardware readings show illuminance values significantly higher than the target 200lux. This indicates strong daylight contribution, especially near windows.

Table 2: Time-series illuminance values extracted from the comparative experimental record.

Time	DIALux (lux)	Measured (lux)
10:00	878	770
10:30	763	743
11:00	848	818
11:30	757	557
12:00	737	563
12:30	646	437
13:00	277	209
13:30	277	203
14:00	277	199
14:30	277	193
15:00	277	188
15:30	277	183
16:00	277	178
16:30	277	173
17:00	277	168

The time series data show the same overall daily pattern in simulation and measurement: illuminance is highest during the late morning period and decreases progressively toward the afternoon. The measured values are consistently lower than the DIALux values during much of the test period, which is expected because the simulation represents idealized geometric, photometric, and daylight assumptions, whereas the physical room is affected by sky conditions, reflections, shading, sensor position, and other environmental factors.

As shown in Table 2, the measurements show that daylight availability was particularly strong during the morning period. After approximately 1:00PM, the measured illuminance decreased toward the 200lux design target and subsequently fell below it during the later observations. This pattern identifies periods in which an adaptive lighting-management system could reduce artificial-light output when daylight is sufficient and increase support when daylight becomes inadequate. Such a control action is proposed as a subsequent implementation stage rather than claimed as the primary experimentally validated result of this paper.

5. Conclusion

This study presented and experimentally evaluated a LoRa-based IoT framework for real-time lux monitoring and energy efficient lighting management. The framework integrates BH1750 digital illuminance sensing, embedded processing, SX1278 LoRa communication, and a monitoring interface to provide continuous information on indoor lighting conditions. The office room experiment used a DIALux model with a 200lux target and compared simulated illuminance with real measurements under artificial light and daylight assisted conditions.

The BH1750 sensing unit showed an average error of approximately 3.18% when compared with a standard lux meter. During the office time-series experiment, 15 half-hour comparison observations were obtained between 10:00AM and 5:00PM. The simulated and measured illuminance values closely match. The LoRa link operated at 433 MHz, and no packet-loss event was observed during the logged test run.

The results demonstrate that real-time lux monitoring can identify daylight availability and periods of potential artificial light reduction. The framework therefore provides a practical measurement and communication layer for daylight responsive lighting management in offices, industrial workspaces, campuses, and other distributed environments. Automatic dimming, relay based control, occupancy sensing, longer duration energy measurements, and multi node field evaluation remain appropriate directions for future work.

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