# Sustainable Lighting Retrofit for Energy Efficiency in Institutional Buildings

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**ABSTRACT**
Lighting systems are essential for ensuring visibility, comfort, and safety in buildings, yet they account for a significant share of overall energy consumption. Improving the efficiency requires not only adopting low-consumption technologies but also implementing strategies aligned with actual usage patterns. At Universiti Teknikal Malaysia Melaka (UTeM), the lighting infrastructure at Satria Residence College relied heavily on conventional fluorescent lamps without proper control, leading to substantial energy waste. This study proposes and implements a cost-effective retrofit that replaces fluorescent lamps with light-emitting diode (LED) luminaires to enhance energy efficiency and occupant comfort. The research was conducted in phases: assessing the existing layout and consumption using DIALux Evo software, replacing the current fixtures with LED alternatives, and testing new configurations to further reduce energy use. The simulation results showed significant reductions in electricity consumption while maintaining proper lighting performance and uniformity. This project demonstrated a scalable, software-based approach to improving lighting efficiency that supported UTeM's long-term sustainability efforts. It directly supported Sustainable Development Goal 7 (Affordable and Clean Energy) by promoting better energy management practices in institutional settings. In conclusion, the outcomes confirmed that substantial energy savings could be achieved while maintaining occupant comfort, contributing to more sustainable and responsible energy consumption.

**KEYWORDS:** Lighting system, DIALux Evo, Energy waste, Energy efficiency, LED

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## 1. INTRODUCTION

In recent years, global energy demand has expanded substantially. A well-designed lighting system can conserve energy while also providing optimal visual comfort to building residents. Lamp technologies also contribute to the energy efficiency in buildings (Wagiman et al., 2020). Although the future of lighting holds great promise, relying solely on technical efficiency is insufficient to fully unlock its energy-saving potential (Martirano, 2011). Efficient lighting is also an important aspect in minimizing energy usage and atmospheric emissions. In the framework of Sustainable Development Goals (SDGs) established by the United Nations, increasing attention has been directed toward energy, social, economic, and environmental benefits of adopting light-emitting diode (LED) lighting systems (Cumo et al., 2025).

In residential colleges within Malaysian universities, general lighting accounts for more than half of total energy consumption. Efficiency can be achieved by using high-performance lighting equipment and correct lighting design strategies that provide the necessary illuminance levels (Uydur, 2022). On the other hand, effectiveness relates to reducing unnecessary energy use through automated lighting controls that respond to occupancy and daylight availability, as well as the integration of technological building management systems (Soheilian et al., 2021).

Progress in the lighting industry has heightened interest in energy-efficient artificial lighting systems in both new and existing applications. The use of LED light sources has become an attractive alternative due to their potential to reduce lighting system maintenance costs and enhance sustainability, although they often require higher initial investment costs (Fantozzi et al., 2017). However, at Satria Residence College, Universiti Teknikal Malaysia Melaka (UTeM), the continued use of conventional fluorescent lamps has resulted in increased power losses and inefficient energy consumption, leading to higher operational costs and greater reliance on non-renewable electricity supply. As a result, energy-efficient lighting design is no longer optional but a necessity for effective and sustainable building management (Mansur et al., 2021). Furthermore, designing different lighting combinations during the design stage can improve overall energy performance while ensuring adequate visual comfort for occupants (Gassar et al., 2021).

New improvements in LED technology provide solutions that are more energy efficient than fluorescent lamps (Uydur, 2022). Furthermore, LED luminaires also last longer and consume less energy. Simply replacing fluorescent lamps without addressing usage requirements does not resolve energy inefficiencies (Rangari et al., 2021). In addition to cost and energy savings, lighting systems should be reviewed and optimized for comfort and functionality. In educational and residential environments, lighting must balance energy efficiency with the promotion of student health and productivity (Birkha Mohd Ali et al., 2021). Optimized lighting designs can simultaneously support physiological well-being and visual performance, demonstrating that energy efficiency improvements need not compromise occupant comfort (Marín-Doñágueda et al., 2021).

Finally, the existing lighting system was originally designed without full integration of energy-efficient hardware. For example, some universities like UTeM continue to rely on fluorescent lighting in their residential colleges. This situation presented an opportunity to transition to LED luminaires as a practical upgrade solution to reduce energy consumption and increase energy efficiency. Therefore, this study focuses on evaluating the existing fluorescent lighting system at Satria Residence College by simulating its performance and assessing the impact of replacing it with LED luminaires using DIALux Evo software. The main objective is to propose a cost-effective and sustainable lighting configuration that enhances both performance and occupant comfort while supporting UTeM's long-term sustainability goals.

## 2. METHODOLOGY

This section explains the methodology, beginning with the data collection and concluding with the simulation of a retrofitted LED lighting system at Satria Residence College, UTeM. The primary objective is to develop a lighting system that improves energy efficiency while maintaining visual comfort for students, particularly in shared spaces like corridors and the cafeteria. The process begins with an analysis of the current lighting layout, which is then imported into DIALux Evo to simulate current lighting performance using fluorescent lamps. Subsequently, the same configuration is re-simulated using LED luminaires to provide a clear comparison of lux levels and energy consumption. Lighting systems are among the major contributors to building energy consumption. Moreover, in a Malaysian institutional case study (Birkha Mohd Ali et al., 2021), lighting accounted for 18% of the total electricity use, which highlights the importance of energy-efficient lighting retrofits such as LED upgrades. This finding is further supported by a study conducted by the University of Michigan, which demonstrated that LED lighting can be up to 44% more energy efficient than traditional 4-foot fluorescent tubes, reinforcing its suitability as a practical and effective solution for building retrofit applications (Atherton, 2023).

### 2.1 Research Design

The research methodology began with the development of a flowchart to clearly illustrate each stage of the retrofitted LED lighting system implementation, as shown in **Figure 1**. The study begins with the identification of the existing lighting infrastructure at Satria Residence College, UTeM. This includes gathering essential layout data, observing energy usage behavior, and preparing scaled floor plans.

The next step involves modeling and analyzing the current lighting system in DIALux Evo software. The simulation assesses the energy performance of the fluorescent luminaires and ensures compliance with MS 1525, the Malaysian standard for energy efficiency in buildings. Once the standard system is evaluated, the fluorescent luminaires are replaced with LED models in the simulation to assess post-retrofit improvements in illuminance levels and power consumption. The designed system is evaluated by checking whether the simulation results meet the minimum lighting requirements based on the MS 1525 standard. If the lux levels are not achieved, the configuration is adjusted repeatedly. Once the performance satisfies the criteria, the configuration is finalized and proposed as the most efficient lighting solution for the selected study area.

The LED luminaires used in this study have a rated power of 28 W and a luminous output of 4250 lumens, resulting in a high luminous efficacy of 152 lm/W. These luminaires were selected to replace the existing twin 28 W fluorescent lamps, which consume a total of 56 W, while providing comparable brightness with approximately half the energy consumption. In addition to improved efficiency, the selected LEDs have a color rendering index (CRI) of 80, offering clear and comfortable illumination. These characteristics make the LEDs a practical option for retrofitting indoor institutional spaces, such as student residential facilities.

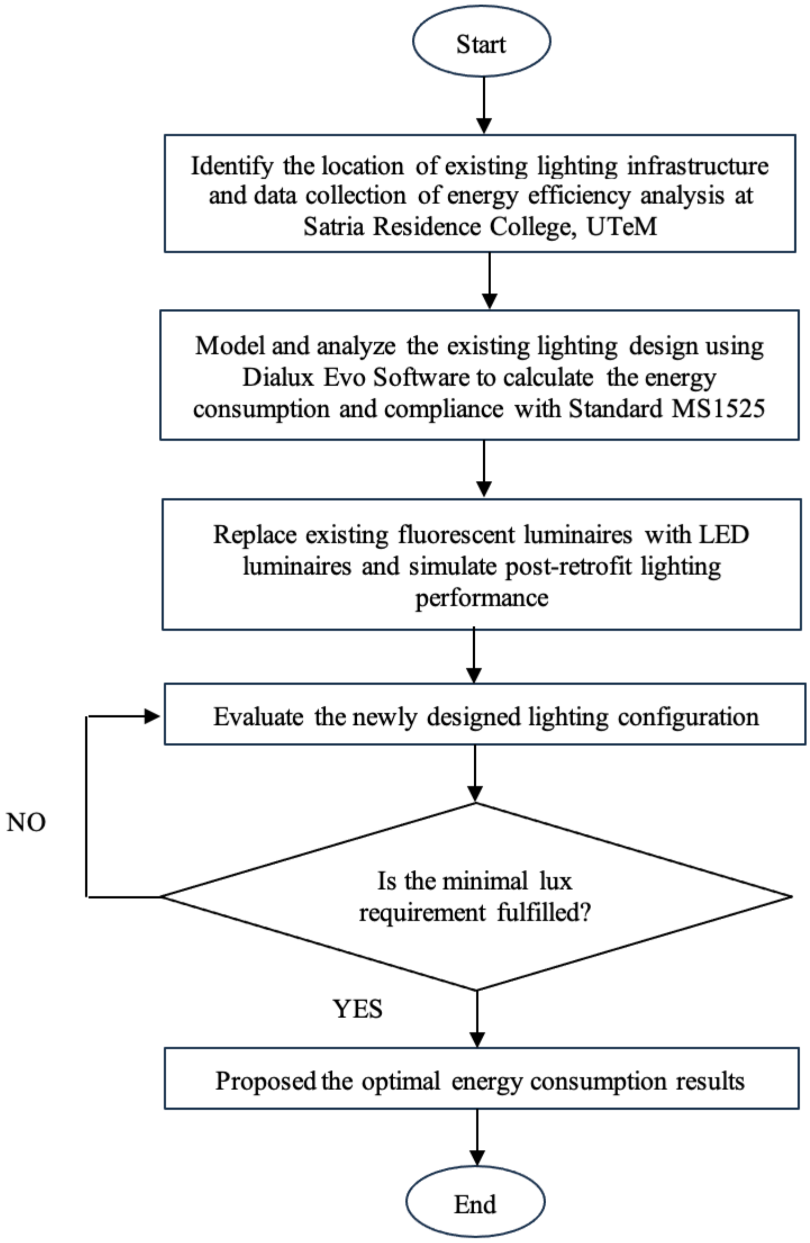


***Figure 1:*** *Flowchart of the study*

## 2.2 Tools and Software

This study employs DIALux Evo for lighting simulation, selected based on its suitability for conducting lighting analysis. The software enables integrated simulation and performance evaluation prior to real-world implementation (Saputri & Radithya, 2024). DIALux Evo was used to simulate the lighting performance of both the existing and proposed lighting configurations at Satria Residence College. The site floor plan in drawing (.dwg) format was imported into the software and scaled to reflect the actual building dimensions. LED luminaires were then configured, and the simulation generated key outputs, including average illuminance (lux), lighting uniformity, and energy consumption. This process enabled a comparative analysis between the traditional fluorescent lighting system and proposed energy-efficient LED luminaires.

## 2.3 Compliance with Malaysian Standard MS1525 for Lighting Guidelines

In this study, compliance with Malaysian and international standards was verified using the requirements specified in MS 1525 (Department of Standards Malaysia, 2014), EN 12464 1 (European Committee for Standardization, 2019), and CIBSE guidelines (European Committee for Standardization, 2019). These standards were adopted as benchmarks to ensure adequate lighting comfort and safety during the DIALux Evo simulations (Hangga et al., 2022). **Table 1** summarizes the minimum illuminance and uniformity requirements for the various spaces within Satria Residential College, UTeM.

### 2.4 Cost Analysis and Payback Assumptions

This study incorporates a cost analysis to assess the financial viability of replacing existing fluorescent lamps with more efficient LED luminaires in Satria Residence College, UTeM. The analysis was based on a 24-hour daily operating schedule, reflecting typical usage patterns in residential colleges where lighting is required continuously.

The annual energy savings per luminaire were determined by calculating the difference in power consumption between the fluorescent and LED luminaires. Following the methodology proposed by Mahlia et al. (2011) the annual energy savings for each lighting point were calculated using Eq. (1):

$$E_{saved} = P \times H \quad (1)$$

Where *P* is the difference in power consumption between fluorescent and LED luminaires, and *H* is the total hours per year. Then, the corresponding cost savings were estimated using Eq. (2):

$$C_{saved} = E_{saved} \times RM0.454 \quad (2)$$

Where RM0.454 per kilowatt-hour (kWh) is the standard tariff set by Tenaga Nasional Berhad for institutional consumers in Peninsular Malaysia. The investment cost per luminaire is approximately RM 85, based on market prices of commercial-grade LED products available in Malaysia. The simple payback period was then calculated using the standard financial expression in Eq. (3):

$$Payback\ Period = \frac{Investment\ Cost}{Annual\ Cost\ Saving} \quad (3)$$

Overall, the adopted methodology integrates lighting performance simulation and economic evaluation to assess the feasibility of retrofitting LED lighting at Satria Residence College, Universiti Teknikal Malaysia Melaka (UTeM). By combining compliance-based lighting analysis with cost and payback assessment, the approach provides a structured framework for evaluating both the technical effectiveness and financial viability of energy-efficient lighting upgrades in continuously operated residential facilities (Harbick, 2025).

## 3. RESULTS AND DISCUSSION

This section presents the simulation results of the retrofitted LED lighting system at Satria Residence College, UTeM. The main objective is to assess the performance of the existing fluorescent lighting system and compare it with an upgraded configuration employing LED luminaires for improved efficiency. DIALux Evo software was used to simulate lighting layouts across various areas of the Satria Residence College, such as residence rooms, hallways, cafeterias, toilets, and walkways leading to the cafeteria. The simulations assess compliance with recommended illuminance and uniformity standards specified in MS 1525:2014 (Department of Standards Malaysia, 2014) and EN 12464-1 (European Committee for Standardization, 2019). Following the evaluation, a new lighting design using LED luminaires was developed.

### 3.1 Case Study 1: Cafeteria of Satria Residence College

The results show that the simulation and analysis were completed for the cafeteria area of Satria Residence College. This space was chosen as the initial focus due to its high occupancy, frequent usage, and relatively high lighting demand. The evaluation of other areas, including student rooms, hallways, toilets, and walkways leading to the cafeteria, is planned for subsequent stages of the study. The findings from the cafeteria serve as a baseline for understanding the existing lighting conditions and identifying potential improvements through the implementation of LED luminaires combined with timer-based controls. Using DIALux Evo, simulations of the existing fluorescent lighting layout were conducted to estimate energy usage and assess compliance with applicable lighting standards. The results showed that while the cafeteria met the minimum illuminance (lux) requirement, the uniformity ratios were relatively low, indicating uneven light distribution. The central areas were over-illuminated, whereas peripheral zones remained insufficiently lit, highlighting inefficiencies in the current lighting design. These findings underscore the need for a more energy-efficient lighting solution.

***Table 1:*** *Standard requirement*

| Space Type | Illuminance Standard | Min. Illuminance (lx) | Uniformity Standard | Minimum Uniformity Ratio ($U_o$) |
|---|---|---|---|---|
| Residence Room | MS 1525 | 100 | EN 12464-1 | 0.6 |
| Toilet | MS 1525 | 100 | EN 12464-1 | 0.6 |
| Cafeteria/Dining Area | MS 1525 | 200 | EN 12464-1 | 0.4 |
| Office/ Study Area | MS 1525 | 300–400 | EN 12464-1 | 0.6 |
| Corridor/Walkway | MS 1525 | 100 | CIBSE | 0.4–0.5 |

### 3.1.1 Current Lighting Configuration using Fluorescent Lamp

The simulation focused initially on the cafeteria, a high-traffic area that significantly contributes to total lighting energy consumption. The existing lighting configuration in the cafeteria consists of fluorescent lamps, each rated at 28 W. A total of 114 fluorescent lamps were installed to provide general illumination across the space. According to MS 1525 (Department of Standards Malaysia, 2014), the recommended average illuminance level for cafeteria areas ranges from 200 to 300 lx to ensure sufficient visibility and occupant comfort. Two lighting scenarios were modeled using the same floor layout and luminaire mounting height: (i) the existing configuration employing twin T5 28 W fluorescent lamps and (ii) a proposed retrofit configuration using 50 W LED luminaires.

As illustrated in **Figure 2**, the fluorescent lighting setup produced moderate illuminance levels; however, the distribution was relatively non-uniform, especially in corner areas. The simulated average illuminance was 326 lx, with a uniformity of 0.47, which falls slightly below the preferred standard of 0.5 for such spaces. In addition, the simulated values increase more than the recommended maximum level. This condition may lead to visual discomfort for occupants and indicates inefficiencies in the existing fluorescent lighting design.

### 3.1.2 New Lighting Configuration using LED Luminaires

In order to address the problem in **Figure 2**, the cafeteria lighting system was redesigned using energy-efficient LED luminaires. Each selected LED unit is rated at 50 W and provides higher luminous output compared to the existing fluorescent lamps. The redesigned layout retains 114 LED luminaires, which were strategically positioned to ensure a more uniform light distribution across the space.

After conducting the DIALux Evo simulation with the updated LED luminaires, **Figure 3** shows a higher and more evenly distributed illuminance level averaging at 526 lux with a uniformity of 0.61. This setup meets the minimum visual comfort requirements specified in MS 1525:2014 and EN 12464-1 for dining and social spaces. These improvements demonstrate the effectiveness of switching to LED luminaires not only for energy savings but also for achieving optimal lighting performance.

### 3.1.3 Comparison Between Fluorescent Lamp and LED Luminaires

The lighting simulation data was further used to analyze energy consumption between the two systems. The parameters compared include illuminance levels, uniformity, power usage, annual energy consumption, and the Lighting Energy Numeric Indicator (LENI) (Witzel, 2012). **Table 2** shows that the LED luminaires produce a significantly higher average illuminance of 526 lux, compared to 326 lux from the fluorescent lighting configuration. This improvement can be attributed to the use of single high-output 50W LED luminaires, which offer higher luminous power compared to the twin-lamp 28 W fluorescent lamps used in the existing system. Although the LED luminaires use more electrical power per unit, the LED system is more effectively designed to deliver focused and uniform illumination, resulting in superior lighting performance per unit of energy consumed (Tara et al., 2020).

Lighting uniformity is also improved, increasing from 0.47 with the fluorescent lamps to 0.61 using LED luminaires, indicating a more consistent light distribution across the cafeteria space (Seyedolhosseini et al., 2020). This enhancement not only enhances visual comfort but also reduces the risk of over- or under-lit zones, which is crucial in high-occupancy environments like dining areas. From an energy efficiency perspective, the annual power consumption decreases from 40,611 kWh under the fluorescent configuration to 33,288 kWh with the LED system, resulting in an annual energy saving of 7,323 kWh. Additionally, the LENI value drops from 28.6 to 23.4 kWh/m²·a, indicating a more energy-efficient lighting system in terms of annual energy use per unit floor area.

However, this overshooting occurred mainly because the LED luminaires used in the simulation had a higher luminous flux output and were applied in the same quantity and position as the current fluorescent lighting setup. Since LED luminaires are more efficient and produce more light per watt, simply replacing fluorescent lamps with higher-power LEDs without adjusting the placement can result in excessive illumination. This explains the higher-than-expected lux levels across the cafeteria space. While the increased brightness can enhance visual, it may also lead to unnecessary energy use and visual discomfort due to glare if not properly addressed.

To address this, future refinement of the lighting layout is recommended, such as reducing the number of luminaires to bring the lux levels closer to the optimal range while maintaining energy efficiency and enhancing occupant comfort (Abdollahzadeh & Biloria, 2024).

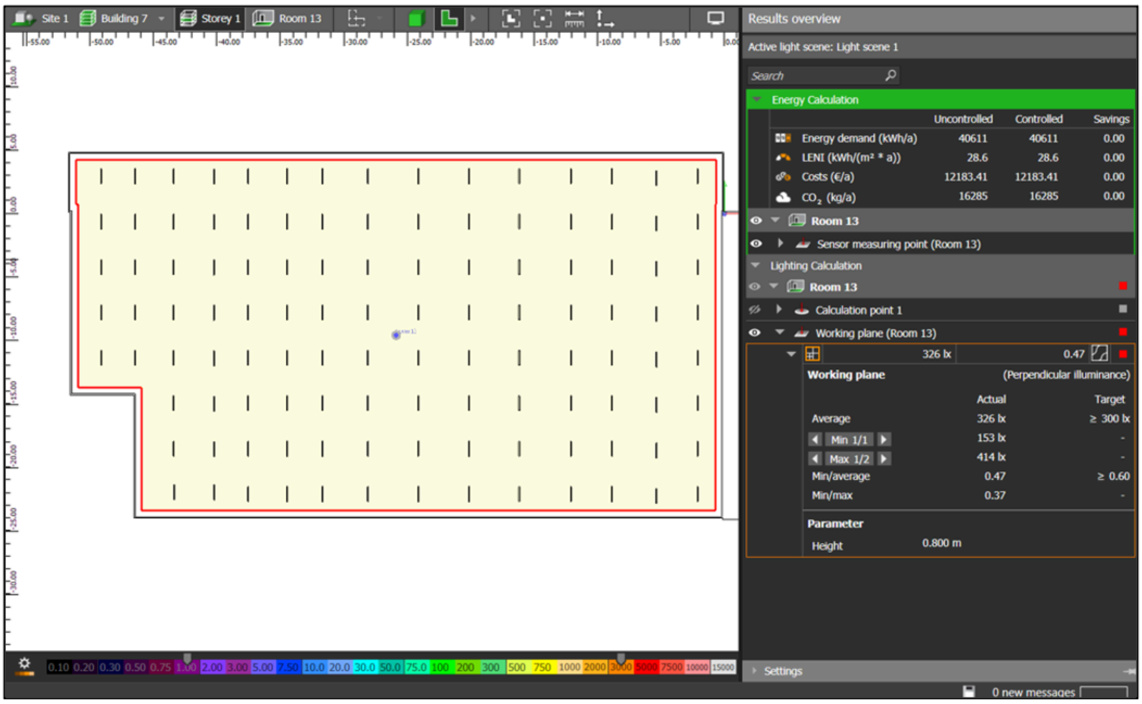


*Figure 2:* *Simulated lighting performance of the Satria Residence College cafeteria using twin T5 fluorescent luminaires*

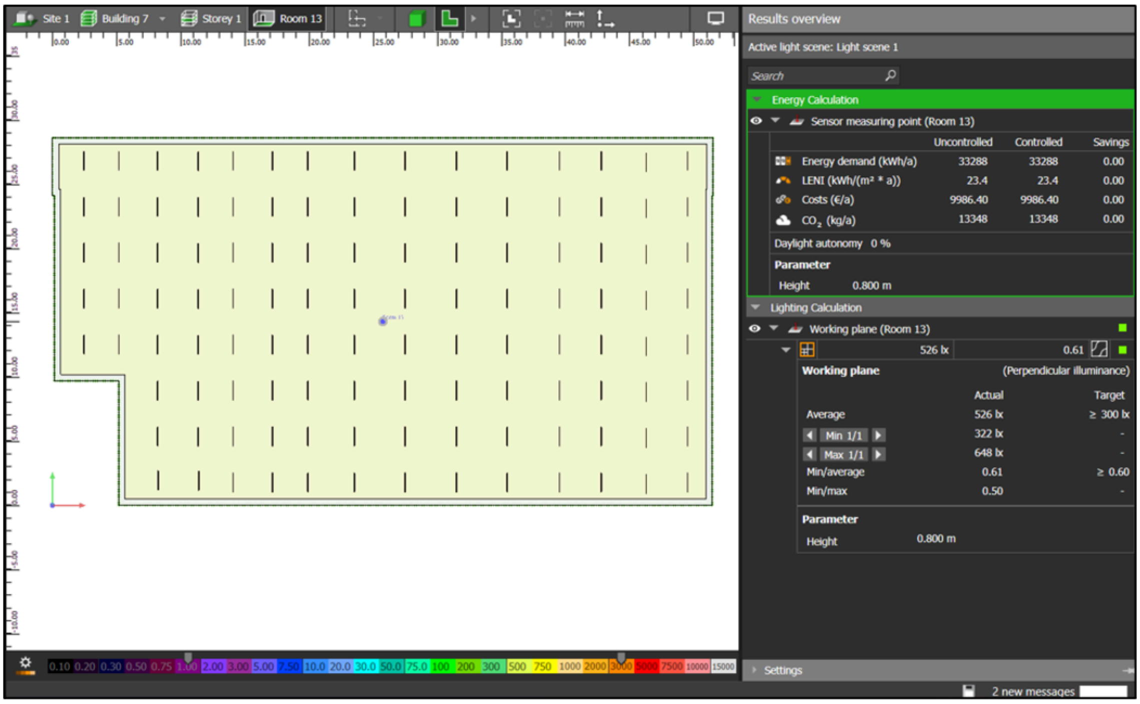


*Figure 3:* *Simulated lighting performance of the Satria Residence College cafeteria after retrofitting with LED luminaires*

*Table 2:* *Comparison between fluorescent lamps and LED*

| Type of Luminaire | Illuminance Level (lx) | Uniformity | Power (kW) | Annual Power (kWh/a) | Energy Consumption LENI (kWh/m² ·a) |
|---|---|---|---|---|---|
| FL T5 28 W | 326 | 0.47 | 6.384 | 40611 | 28.6 |
| LED | 526 | 0.61 | 5.700 | 33288 | 23.4 |

## 3.2 Case Study 2: Corridors of Lekir Building at Satria Residence College

This section presents an analysis of the corridor lighting system in the Lekir building of Satria Residence College. Corridors are high-traffic areas that remain active throughout the day and night, making lighting efficiency important. This study evaluates the performance of the existing fluorescent lighting and explores the benefits of transitioning to an LED-based system.

The corridor simulation using fluorescent lamps served as the reference setup. Results showed that while the current system delivered acceptable average illuminance, the distribution of light was uneven. Brightness was concentrated along the centerline, while edges and corners remained poorly lit. The LED luminaires configuration, using the same number and layout of fittings, has achieved more uniform lighting, improved visibility, and reduced energy consumption. These findings emphasize the value of optimizing corridor lighting not only for visual comfort but also for long-term energy efficiency (Suardi et al., 2025).

### 3.2.1 Current Lighting Configuration using Fluorescent Lamp

The existing corridor lighting system employs T5 fluorescent lamps, each rated at 28 W. A total of 20 twin lamps were installed along the corridor ceiling in a continuous linear arrangement, as illustrated in **Figure 4**. This setup was designed to maintain visibility and safety for students.

Based on the DIALux simulation in **Figure 5**, the fluorescent lamps have achieved an average illuminance of 231 lx, which is above the minimum standard of 100 lx for corridor areas specified in MS 1525 and EN 12464-1. However, the lighting uniformity was relatively low, indicating an uneven distribution of light across the corridor space.

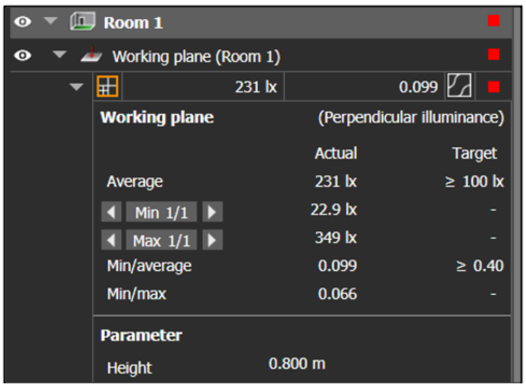


***Figure 5:*** *Lighting calculation for Space 1*

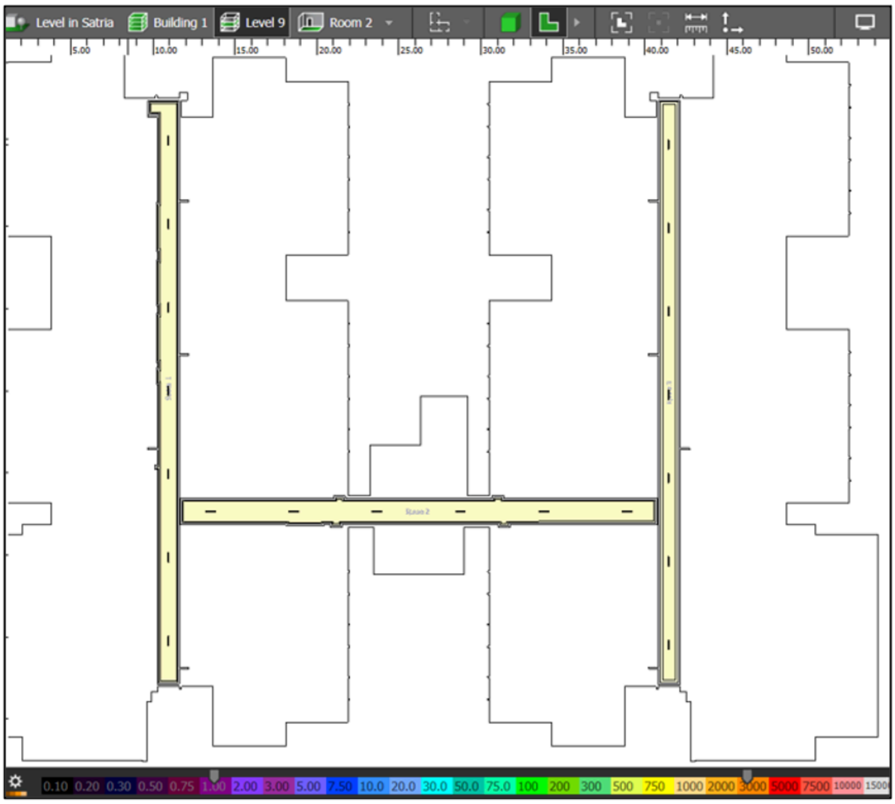


***Figure 4:*** *Simulated corridor lighting layout at Satria Residence College using twin T5 fluorescent luminaires*

**Figure 6** shows that the fluorescent lamps have achieved an average illuminance of 231 lx, exceeding the minimum requirement of 100 lux for corridor areas specified in MS 1525 and EN 12464-1. However, although the uniformity level has increased from 0.099 (**Figure 5**) to 0.55, it remains below the recommended threshold, indicating that the lighting distribution across the corridor is still uneven.

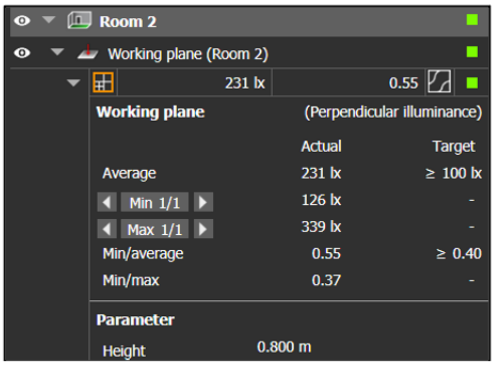


***Figure 6:*** *Lighting calculation for Space 2*

Based on the DIALux simulation shown in **Figure 7**, the fluorescent lighting system achieved an average illuminance of 233 lx, exceeding the minimum standard of 100 lx for corridor areas under MS 1525 and EN 12464-1. In addition, the figure shows an improvement in lighting uniformity compared to the results presented in **Figures 5** and **6**.

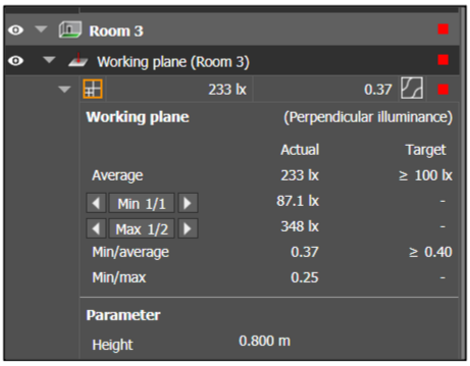


***Figure 7:*** *Lighting calculation for Space 3*

The uniformity ratios observed in **Figures 5**, **6**, and **7** did not meet the minimum recommended requirement of 0.40, indicating uneven lighting conditions along the corridor. Although certain sections of the corridor were adequately illuminated, other areas, particularly near walls and corners, remained comparatively dim. Such imbalances in illuminance distribution can lead to visual discomfort and reduce the overall lighting efficiency and effectiveness of the lighting system.

### 3.2.2 New Lighting Configuration using LED Luminaires

As shown in **Figure 8**, LED luminaires were introduced to address the uneven illumination produced by the fluorescent lamp. The new lighting layout was developed using energy-efficient LED luminaires with the same physical setup. Each LED luminaire, rated at 28 W, offers improved optical control and higher efficiency compared to the existing fluorescent lamps.

The LED luminaires were placed in the same positions as the previous setup shown in **Figure 4** to allow a direct performance comparison. The simulation results, presented in **Figure 9**, indicate a notable improvement in lighting quality with the average illuminance increasing to 396 lx. However, the lighting uniformity remained low, indicating that the illumination distribution was uneven.

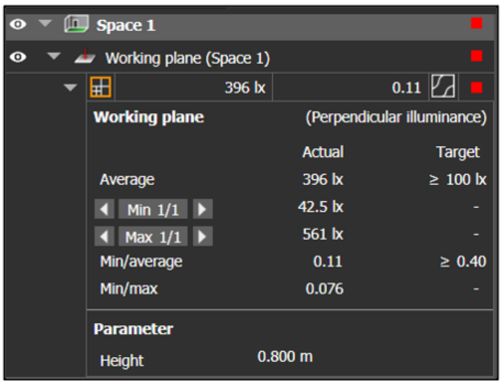


***Figure 9:*** *Lighting calculation for Space 1*

Based on the DIALux simulation in **Figure 10**, the new LED luminaires achieved an average illuminance of 385 lx, exceeding the minimum standard of 100 lx for corridor areas under MS 1525 and EN 12464-1. The lighting uniformity also increased to 0.43 and achieved the requirement of a 0.4 uniformity level.

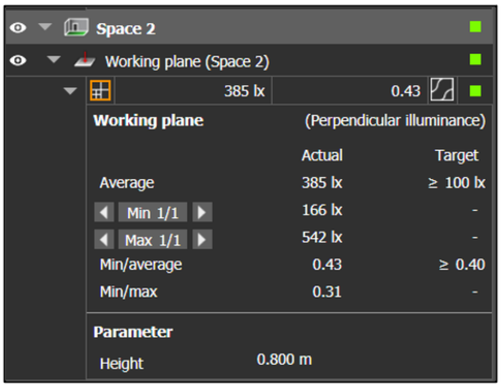


***Figure 10:*** *Lighting calculation for Space 2*

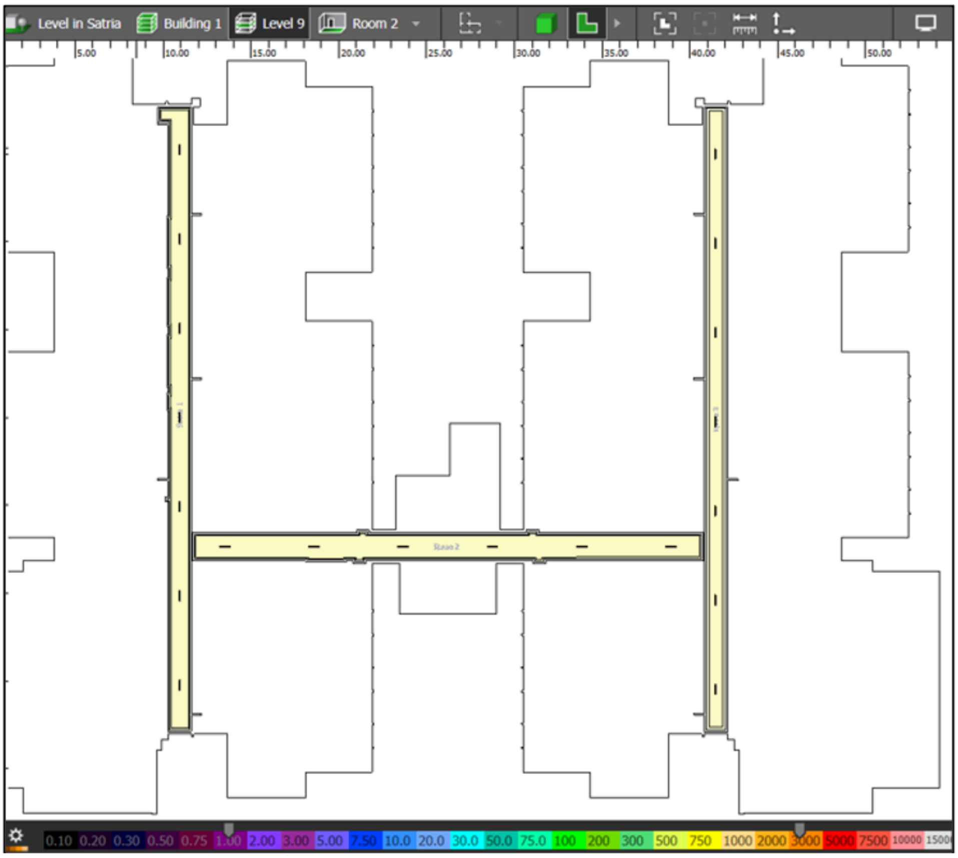


***Figure 8:*** *Simulated corridor lighting layout at Satria Residence College using LED luminaires*

**Figure 11** shows that the LED luminaires have achieved an average illuminance of 409 lx, exceeding the minimum standard of 100 lx for corridor areas under MS 1525 and EN 12464-1. The lighting uniformity level also achieved the requirement of 0.4.

### 3.2.3 Comparison of using Fluorescent Lamp and LED Luminaires

A summary of the comparison between the two types of luminaires is presented in **Table 3**. The LED luminaires outperformed the fluorescent lamps in all areas evaluated. Although both lighting systems operate at the same power rating of 28 W, the LED luminaires provide higher illuminance and improved uniformity due to better light distribution.

The comparison in **Table 3** highlights that although both fluorescent and LED luminaires consume the same power per space, the LED luminaires significantly outperform the fluorescent lamps in terms of illuminance and uniformity. While the T5 fluorescent lamps provide an average of 231–233 lx with uneven light distribution and uniformity as low as 0.10, the LED system delivers 385–409 lx with more consistent uniformity values across all spaces. The LENI value drops from 5.54 to 2.77 kWh/m²·a, indicating a more efficient lighting system in terms of energy used per square meter annually when changing the type of luminaire from FL Lamps to LED luminaires. According to Cui and Ahn (2025), higher energy consumption was linked to spaces with less natural light and uneven brightness, which required additional artificial lighting tools. Conversely, lower power consumption reflected a more uniform and sufficient natural light distribution, creating softer illumination that met user comfort requirements. These findings align with the present study's results, where reduced LENI values and improved uniformity indicate efficient lighting distribution without excessive reliance on artificial sources. Despite having nearly identical annual power consumption due to the same number of fittings used, the LED luminaires offer better lighting quality per watt consumed.

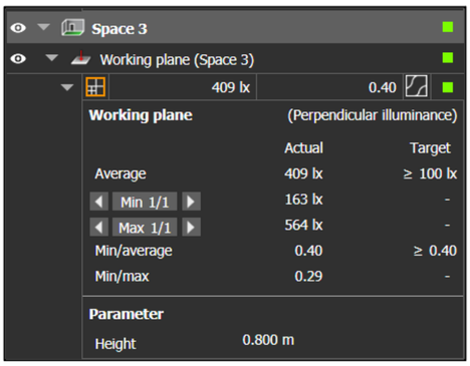


***Figure 11:*** *Lighting calculation for Space 3*

*Table 3: Comparison of using FL and LED*

| Area | Type of Luminaire | Illuminance Level (lx) | Uniformity | Power (kW) | Annual Power (kWh/a) | Energy Consumption LENI (kWh/m² a) |
|---|---|---|---|---|---|---|
| **Space 1** | FL T5 28 W | 231 | 0.1 | 392 | 3433.92 | 5.41 |
| **Space 2** | FL T5 28 W | 231 | 0.55 | 336 | 2943.36 | 4.78 |
| **Space 3** | FL T5 28 W | 233 | 0.37 | 392 | 3433.92 | 5.54 |
| **Space 1** | LED 28 W | 396 | 0.11 | 196 | 1716.96 | 2.71 |
| **Space 2** | LED 28 W | 385 | 0.43 | 168 | 1471.68 | 2.39 |
| **Space 3** | LED 28 W | 409 | 0.40 | 196 | 1716.96 | 2.77 |

Note: FL = fluorescent lamp.

The observed improvements in illuminance levels and lighting uniformity, coupled with reduced energy consumption, confirm the effectiveness of LED luminaires as a viable alternative to conventional fluorescent lighting. These findings demonstrate that the replacement of fluorescent lamps with LED luminaires not only enhances lighting performance but also contributes to improved energy efficiency in institutional residential settings.

The implications of these results highlight that LED retrofit strategies can serve as a cost-effective and scalable model for other educational and residential facilities seeking to enhance energy performance. The study also shows that significant energy savings and better lighting comfort can be achieved without major hardware modifications, which also supports UTeM's smart campus initiative and SDG 7 (Affordable and Clean Energy). However, this study is limited to simulation-based analysis using DIALux Evo software and does not include on-site validation or user feedback. Future research should incorporate real-world testing and long-term monitoring to validate the simulation outcomes and further refine the proposed lighting design for practical implementation.

### 3.3 Cost Saving and Payback Analysis Results

A practical evaluation of the LED retrofit system was carried out to determine its financial practicality under typical institutional operating conditions. The selected LED luminaires, each rated at 28 W, were designed to replace existing fluorescent lamps comprising two 28 W tubes, resulting in a total power reduction of 28 W per unit. Under continuous operation for 24 hours a day, each LED luminaire achieves an annual energy saving of approximately 245.28kWh, as shown in **Table 4**.

*Table 4: Cost saving and payback period calculation for LED retrofit system*

| Parameters | Formula | Value |
|---|---|---|
| Fluorescent lamp power | – | 28 W |
| Operating hours per year | $H = 24x365$ | 8760 h |
| Annual energy saving | $Esaved = \frac{PxH}{1000}$ | 245.28 kWh |
| Annual cost savings | $Csaved = Esavedx0.454$ | RM111.37 |
| Investment cost | – | RM85 |
| Payback period | $Payback = \frac{85}{111.37}$ | 0.76 (≈9 months) |

Based on the current electricity tariff of RM0.454 per kWh, as outlined in Tenaga Nasional Berhad's Regulatory Period 4 for Peninsular Malaysia (Singh, 2025), this results in an annual cost saving of RM111.37 per luminaire. With each LED unit priced at approximately RM85, the payback period is estimated to be within a few months. This relatively short return period highlights the cost-effectiveness of the retrofit, particularly for institutional facilities such as student residential colleges, where lighting remains operational throughout the day. Furthermore, the longer lifespan and reduced maintenance requirements of LED technology contribute to long-term energy efficiency and support broader sustainability objectives.

## 4. CONCLUSION

This project investigated the potential for improving energy efficiency and lighting quality at Satria Residence College, UTeM, through the replacement of conventional fluorescent lamps with LED luminaires. The simulation results indicate that the proposed LED configuration significantly enhanced illuminance levels and lighting uniformity compared to the existing fluorescent system, while maintaining comparable power consumption per fitting. These findings highlight the value of transitioning to modern lighting technologies in institutional settings, offering improved visual comfort and greater energy efficiency. The outcomes support ongoing efforts to promote sustainable practices within campus environments and align with SDG 7 (Affordable and Clean Energy) by encouraging responsible and efficient use of lighting systems.

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