

Simulation-Based Evaluation of LED Lighting Retrofit for Energy Efficiency in Institutional Residences

Nur Zawani Binti Saharuddin¹, Fatin Damiea Binti Nasruddin¹, Izdihar Binti Kamal²,
Ezreen Farina Binti Shair¹

¹Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia

²Faculty of Science, Universiti Putra Malaysia, Selangor, Malaysia

Email: nurzawani@utem.edu.my

How to cite this paper: Saharuddin, N.Z.B., Nasruddin, F.D.B., Kamal, I.B. and Shair, E.F.B. (2026) Simulation-Based Evaluation of LED Lighting Retrofit for Energy Efficiency in Institutional Residences. *Journal of Power and Energy Engineering*, **14**, 29-41. <https://doi.org/10.4236/jpee.2026.146003>

Received: May 10, 2026

Accepted: June 27, 2026

Published: June 30, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

The consumption rate of energy in higher education institutions has been rising steadily in recent years as a result of the expansion of campus facilities, increased working hours, and the increase in the number of students. In these settings, residential structures constitute a large proportion of aggregate electricity consumption, with lighting systems running over extended hours, and with lighting systems having a direct impact on energy consumption and comfort of occupants. Consequently, the enhancement of the performance of lighting systems has become one of the priority areas of the institutional energy efficiency programs. Lighting system performance dictates energy consumption in institutional residences, and as such, it is one of the priority areas in which efficiency can be improved. Satria Residence College is a campus that is now using traditional Fluorescent (FL) lamps at Universiti Teknikal Malaysia Melaka (UTeM), which are adding to the overconsumption of power and increasing maintenance expenses. To overcome these difficulties, it is necessary to replace FL lamps and conduct a regular analysis of other designs prior to implementation. The paper is a simulation analysis of a retrofitting measure, which substitutes FL luminaires with Light Emitting Diode (LED) luminaires. A preliminary model of the existing setup was developed with the DIALux Evo to determine baseline values of the illuminance, uniformity, and energy requirements. It therefore led to re-simulation of the same layout with LED luminaires under the same conditions, and this provided a direct comparison of the two lighting qualities and energy performance. The assessment model focused on the adherence to the Malaysian Standard MS1525, although the visual comfort requirements were also met. The findings reveal that retrofitting to LED luminaires results in quantifiable changes in lighting performance in

terms of energy efficiency. These results show the usefulness of simulation-based assessment when looking at retrofit decisions in relation to institutional homes. The research not only provides a methodological source of information on sustainable lighting upgrade within UTeM but also advances the broader objective of energy efficiency in campuses.

Keywords

Lighting Retrofit, Energy Efficiency, LED Luminaire, DIALux Evo, Institutional Residences

1. Introduction

The increased interest in sustainability has placed lighting efficiency in greater focus, especially in institutions and home settings where energy consumption has been striving to increase [1]. Research indicates that well-designed lighting can save a lot of energy and increase occupant comfort, which is a major aspect of sustainable building design [2] [3]. Nevertheless, technical efficiency is not enough to overcome the difficulties of modern energy management, and more comprehensive strategies should be developed to reveal the complete potential of lighting systems [4]. The shift to Light Emitting Diode (LED) technology is trending in the international sustainability agenda as it has cost, social and environmental advantages [5].

Residential colleges are one of the highest energy-intensive buildings in Malaysian universities, and the lighting in these buildings comprises over 50% of the total use [6]. Therefore, the need to respond to this demand involves efficient equipment as well as considerate design practices. When combined with proper planning of layout, high-performance luminaires can provide the adjustment to the recommended illuminance levels [7]. Simultaneously, studies emphasize the necessity of minimizing the number of unwarranted energy consumption in accordance with innovative approaches like the ability to combine the building management system [8]. The use of the traditional Fluorescent (FL) lamps at Satria Residence College, Universiti Teknikal Malaysia Melaka (UTeM), is still adding more to the expenditure and energy consumption, which explains the need to implement sustainable retrofitting programs as soon as possible [9].

The development of LED technology also offers a feasible solution to such developments [10] [11]. LEDs are also more robust, use less energy and have a greater luminous efficacy compared to FL lamps [7]. It is also very appropriate to use as a simulation-based evaluation, as it allows the designers to know how it will perform before actual implementation. The previous research has proven that retrofitting with LED produces beneficial effects on the environment and economy as it reduces maintenance expenses and energy consumption over the long term [12].

The human aspect of the lighting design should also be considered. Lighting quality has been demonstrated to determine the productivity, health and well-being of students in residential and educational settings [13]. It was shown that energy efficiency could be attained without compromising visual comfort, and optimized lighting has a positive impact on both physiological and performance results [14]. It is important to note that this compromise between efficiency and comfort is especially critical in the university residences, where lighting is vital to the day-to-day activities of the students [15].

In organizations such as UTeM, these factors present an opportunity to replace traditional fluorescent (FL) lamps with LED luminaires. With the aid of simulation and modelling software such as DIALux Evo, it is possible to model the performance of different lighting configurations, analyse them in accordance with lighting standards, and validate the results [16]. Accordingly, this paper examines the retrofit of LED luminaires in Satria Residence College, with particular emphasis on simulation-based evaluation to ensure compliance, improve energy efficiency, and enhance occupant comfort [17]. This study focuses specifically on the living halls and toilet spaces in the Lekir Building at Satria Residence College, UTeM, as representative residential spaces with continuous lighting usage. The study boundary is limited to evaluating the existing fluorescent lighting system and its replacement with LED luminaires using DIALux Evo simulation under identical spatial conditions.

2. Methodology

This chapter explains how the study was carried out, starting with data collection and proceeding to how the simulation of a smart lighting system at Satria Residence College, UTeM, was carried out. This was aimed at creating a lighting arrangement that enhances energy efficiency. In the meantime, it is significant to maintain the visual comfort of the students, especially in the common facilities, like student living halls and the student toilets. This methodology involved the analysis of the current lighting layout that was imported into DIALux Evo and simulated current performance with FL lamps. The same setup was again simulated with LED luminaires so that a direct comparison of the illuminance levels, the quality of lighting and energy consumption can be made.

2.1. Research Design

The research design will describe further avenues to be taken in this research, including evaluating the current lighting system through the simulation and evaluation of retrofitted alternatives. It acts as a guide by which all stages of the work are linked together so that the objectives are approached logically and in an organized manner. The entire process is depicted in **Figure 1**, displaying the flowchart of the study.

The research process will commence with the identification of the current lighting infrastructure at the Satria Residence College, UTeM. The information about

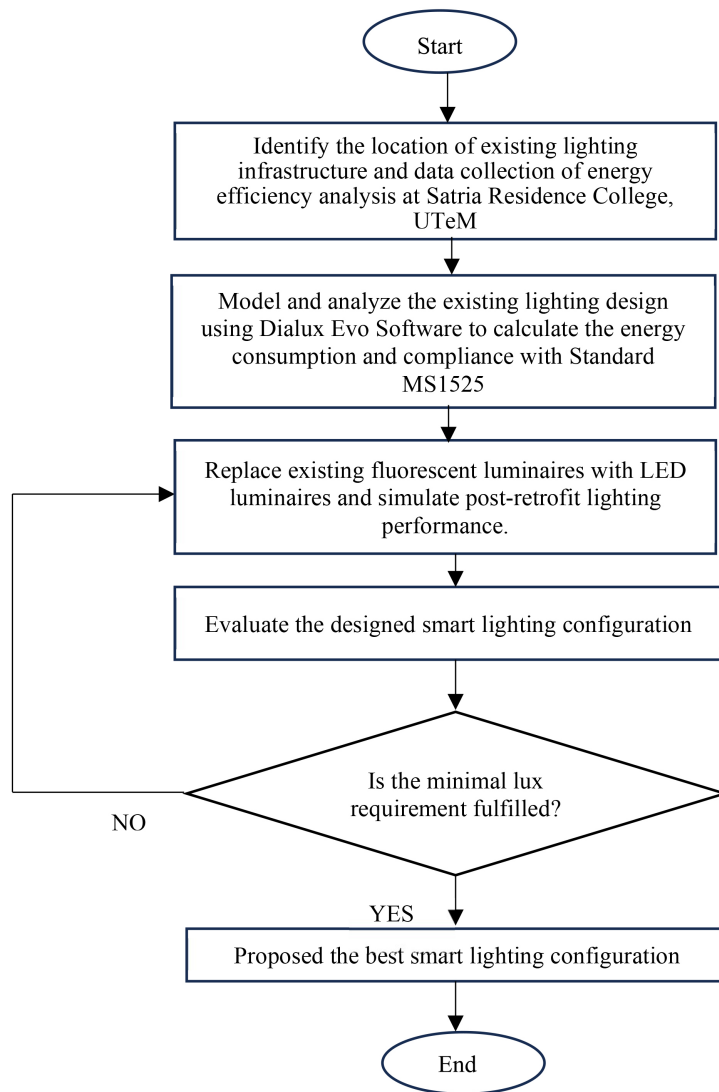


Figure 1. Flowchart of the study.

the quantity, the character, and the layout of FL lamps were taken at this stage to develop a transparent image of the existing system and its energy efficiency. This is an important step towards the identification of the given state of affairs before any changes are suggested.

The second step was to model the current setup of DIALux Evo software [18]. Simulating the current design using FL lamps, the energy consumption and the compliance with the Malaysian Standard MS1525 [19] were calculated. It is based on this baseline analysis that a comparison of the current installation and other designs was done [20].

The simulation environment had FL lamps, which were switched with LED luminaires once the baseline had been set. This step allowed the post-retrofit performance to be assessed at the same spatial and operational conditions. Parameters like levels of illuminance, energy requirement and uniformity of distribution were evaluated to establish how the retrofit could enhance overall efficiency.

The next step was dedicated to the analysis of the developed LED-based lighting setup. This analysis was done by observing that the proposed retrofit was in compliance with the minimum lux requirements as stipulated in residential and educational building standards. The result of this step decided whether the design would continue or it would need additional changes.

Lastly, in case the minimal lux requirement was met, the suggested setup was adopted as the most appropriate design to be used in the study. This was the conclusion of the study process, which offered a reviewed lighting solution that ensures energy saving and yet students in Satria Residence College are comfortable with the visuals.

The DIALux Evo simulations were developed using the actual dimensions and lighting layouts of the selected living halls and toilet spaces in Lekir Building. The simulation inputs included room dimensions, luminaire quantity and placement, mounting height, lamp wattage and luminous flux, surface reflectance values for ceiling, wall, and floor finishes, maintenance factor, and working plane height. Existing FL luminaires rated at 28 W and proposed LED luminaires rated at 20 W were simulated under identical spatial configurations to ensure a fair comparison. Standard indoor assumptions available in DIALux Evo were applied, while daylight contribution and automatic lighting control systems were excluded to maintain consistency between baseline and retrofit simulations.

2.2. Compliance with Malaysian Standard for Lighting Guidelines

The assessment of the lighting design was based on the Malaysian Standard MS1525 [19], which specifies the illuminance and lighting uniformity requirements for residential and educational buildings. These criteria were applied during the DIALux Evo simulation process to ensure that the proposed LED retrofit satisfied the required visual comfort and safety conditions [21]. In addition to MS1525:2014, several lighting standards were incorporated to provide a more comprehensive evaluation of lighting performance. EN 12464-1 was referenced for indoor lighting quality and uniformity assessment, while CIBSE recommendations were applied to circulation and walkway spaces. This combination of standards enabled the study to address both local compliance requirements and international visual comfort practices. **Table 1** summarizes the minimum illuminance and uniformity criteria for the functional spaces evaluated in Satria Residence College, UTeM.

Table 1. Standard regulation.

Space Types	Illuminance Standard	Min. Illuminance Lux (lux)	Uniformity Standard	Min. Uniformity Ratio (U_o)
Residence Room		100		
Toilet	MS1525	100	EN 12464-1	0.6
Cafeteria/Dining Area		200		0.4

Continued

Office/Study Area	300 - 400		0.6
Corridor/Walkway	100	CIBSE	0.4 - 0.5

2.3. Cost Payback Analysis

To determine the financial viability of the proposed changes on the replacement of the current FL lamps with LED luminaires in Satria Residence College, UTeM, a cost analysis was done. As a result, the baseline energy consumption of the FL was compared to the simulated performance of the LED system. The analysis was based on a 24-hour daily operating schedule, which represents normal usage in a residence college where lighting is always necessary. The annual energy savings for each luminaire were calculated by comparing the power consumption of FL and LED luminaires. The annual energy savings for each lighting point were computed using Equation (1) [22]:

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

where P is the power differential between FL and LED luminaires and H is the total number of hours in a year. The corresponding cost savings were computed using Equation (2):

$$C_{\text{saved}} = E_{\text{saved}} \times \text{RM}0.365. \quad (2)$$

Tenaga Nasional Berhad sets a standard tariff of RM0.365 per kilowatt-hour (kWh) for institutional consumers in Peninsular Malaysia. The investment cost per luminaire is estimated at around RM100, which depends on market rates for commercial-grade LED products available in Malaysia. The simple payback period was then determined using the conventional financial expression in Equation (3) [7].

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

This section describes the entire study process utilized in the strategic installation of a retrofitted LED lighting system at Satria Residence College, UTeM. The process has started by evaluating the current lighting structure and efficiency. Simulations of FL and LED luminaire configuration using DIALux Evo. To guarantee illuminance and uniformity provisions, such simulations were compared with the Malaysian Standard MS1525:2014 [19], European Standard: EN 12464-1 [23], and Chartered Institution of Building Services Engineers (CIBSE) standards [24]. It is worth noting that the analysis of costs and payback assumptions was created to ascertain the economic viability of the upgrade of LED lighting in the student houses [22], especially in the scenario of student houses where lighting is on at all times of the day.

3. Results and Discussion

The following section depicts the findings of the simulation process of the retro-

fitted LED lighting system within the Satria Residence College, UTeM. The main objective of the given study was to assess the existing lighting performance of FL lamps and compare it to an improved system in which LED luminaires were used to make the performance more efficient. Lighting arrangements were simulated in the various areas of the Satria Residence College, such as living halls and toilets, using the DIALux Evo software. These simulations will find out whether it meets the requirements of the MS1525:2014 [19] and the EN 12464-1 [23] lighting standard. A new lighting model was developed after the review based on LED luminaires. In this research, the Lekir Building was selected as the representative case study because it contains highly occupied residential spaces with long daily lighting operating hours, particularly in the living halls and toilet areas. These spaces represent common lighting conditions across Satria Residence College and therefore provide a practical basis for evaluating retrofit performance. The findings obtained from the selected case spaces were subsequently extended to the full lighting inventory of the residential college, involving an estimated total replacement of 718 luminaires, in order to estimate campus-level energy savings and economic benefits.

3.1. Case Study 1: Living Halls in Lekir Building at Satria Residence College

The Lekir building was tested to evaluate the lighting performance in the living hall to determine efficiency in terms of energy consumption and visual comfort. The living hall is often used as a common room wherein students have group discussions, social gatherings and other occasions. The existing FL lamps and a suggested LED retrofit were compared.

1) Current Lighting Configuration using Fluorescent Lamp

The recreational and social activities that involve the living halls in **Figure 2** have to be provided with a comfortable and reliable lighting environment. According to the MS1525 guidelines [19], it is recommended that the minimum illuminance level should be 100 lux and the uniformity ratio should be at least 0.6. The FL lamps simulation indicated that the average illuminance of the lamps was 217 lux, with a uniformity of 0.78. These values reveal that the FL current setting of the living halls is bright and corresponds to the minimum requirements in terms of providing students with the necessary comfort.

2) New Lighting Configuration using LED Luminaires

Simulation of LEDs in **Figure 3** showed that the living halls had an average illuminated value of 269 lux and a uniformity ratio of 0.8. These values are beyond the minimum of 100 lux and 0.6 uniformity of MS1525, indicating that the conditions of lighting are appropriate for social activities.

3) Comparison of using Fluorescent Lamp and LED Luminaires

The lighting simulation data was also examined to draw a comparison on energy performance between current FL lamps and the proposed LED luminaires, as presented in **Table 2**. The parameters assessed include illuminance levels, uni-

formity, power usage, annual energy consumption, and energy consumption. The detailed discussion of illuminance and uniformity has been presented in earlier sections, and both systems met the minimum requirements outlined in MS1525. The LED retrofit was intended to provide at least equivalent lighting service while improving energy efficiency. Due to the higher luminous efficacy of LED luminaires compared to FL lamps, the simulated LED configuration produced higher illuminance levels despite operating at lower power consumption. This demonstrates that improved visual performance can be achieved simultaneously with reduced energy demand.

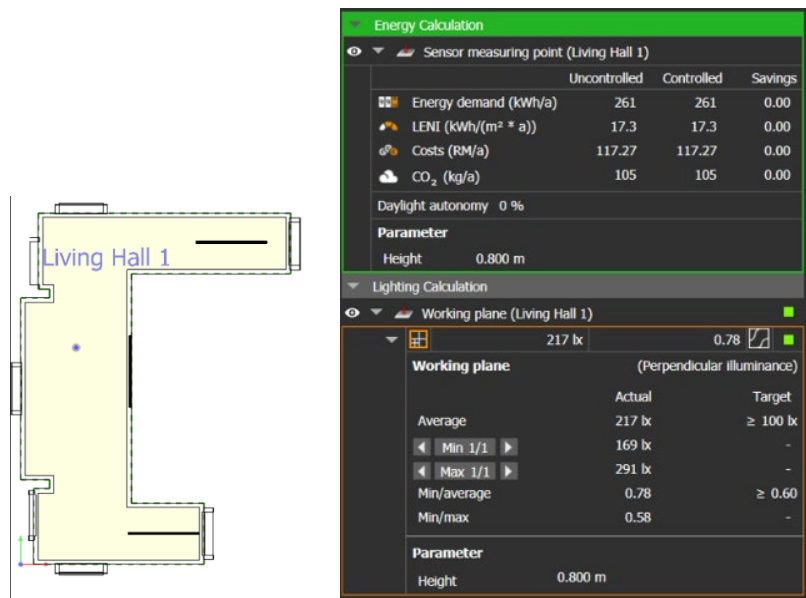


Figure 2. Living halls using FL lamps.

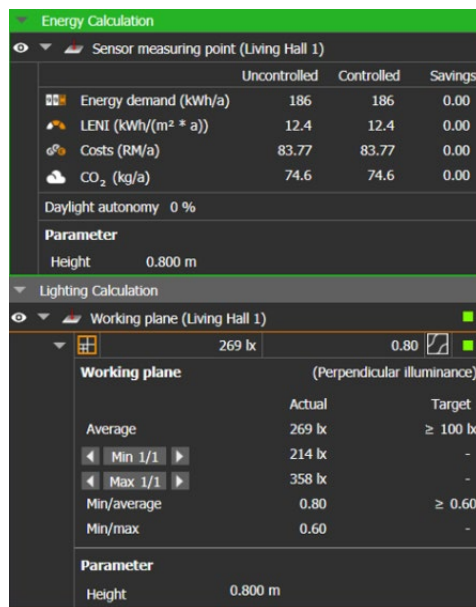


Figure 3. Living Halls using LED Lamps.

Table 2. Comparison of using FL and LED at living halls.

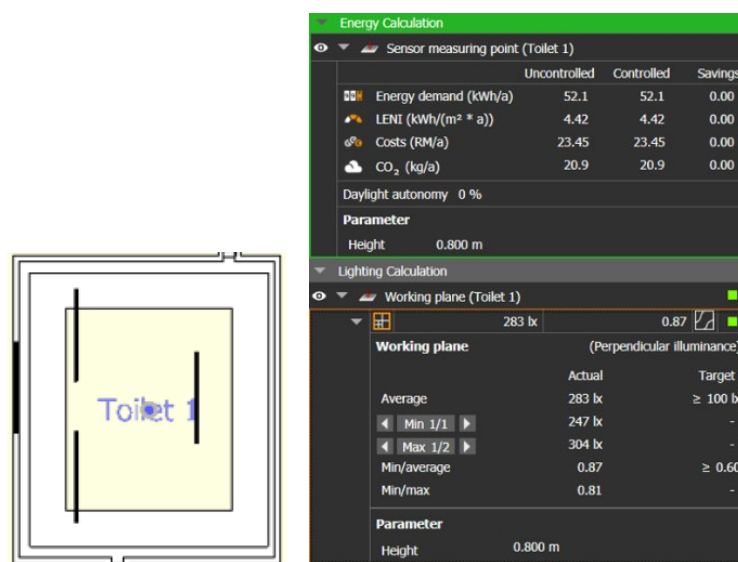
Type of Luminaire	Illuminance Level (lux)	Uniformity	Annual Power Consumption (kWh/a)	Energy Consumption (kWh/m ² ·a)
FL 28W	217	0.78	26,100	17.3
LED 20W	269	0.80	18,600	12.4

3.2. Case Study 2: Toilets in Lekir Building at Satria Residence College

An evaluation of the toilets in the Lekir building was also conducted. Adequate lighting in these spaces is essential to support safety, hygiene, and comfort. However, it often represents an overlooked area for potential energy savings. This case study, therefore, compared existing FL lamps with LED-based designs to determine the extent of improvement achieved through retrofitting.

1) Current Lighting Configuration using Fluorescent Lamp

Toilets require consistent illumination to support safety and functionality in daily use. **Figure 4** illustrates an average illuminance of 283 lux with a uniformity of 0.87. These values indicate that the toilets are highly illuminated and well above the recommended minimum, suggesting potential over-illumination in the current configuration.

**Figure 4.** Toilets using FL lamps.

2) New Lighting Configuration using LED Luminaires

The toilets were simulated using LED luminaires in **Figure 5**, which recorded an average illuminance of 348 lux with a uniformity ratio of 0.85. These values are well above the MS1525 minimum requirement of 100 lux with 0.6 uniformity, suggesting that the lighting conditions are more than sufficient for safe and effective use of the toilet facilities.

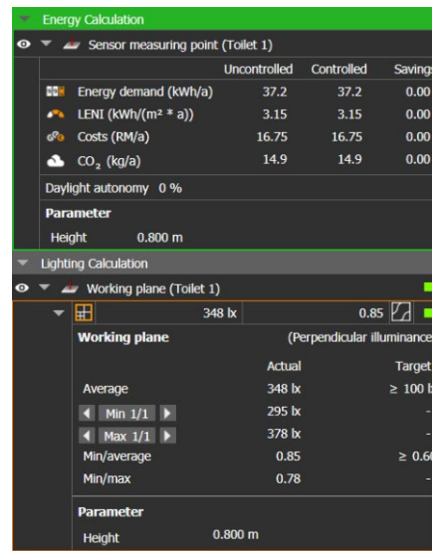


Figure 5. Toilets using LED luminaires.

3) Comparison of using Fluorescent Lamp and LED Luminaires

The lighting simulation data was further analyzed to compare energy performance between the existing FL lamps and the proposed LED luminaires, as shown in Table 3. The parameters assessed include illuminance levels, uniformity, power usage, annual energy consumption, and the energy consumption. The detailed discussion of illuminance and uniformity has been presented in earlier sections, and both systems met the minimum requirements outlined in MS1525. Lighting simulation data was also examined to draw a comparison on energy performance between current FL lamps and the proposed LED luminaires, as presented in Table 3. The parameters assessed include illuminance levels, uniformity, power usage, annual energy consumption, and the energy consumption. The detailed discussion of illuminance and uniformity has been presented in earlier sections, and both systems met the minimum requirements outlined in MS1525.

Table 3. Comparison of using FL and LED at toilets.

Type of Luminaire	Power (W)	Illuminance Level (lux)	Uniformity	Annual Power Consumption (kWh/a)	Energy Consumption (kWh/m²·a)
FL	28	283	0.87	5210	4.42
LED	20	348	0.85	3720	3.15

3.3. Cost Payback Analysis Results

The payback analysis for the FL to LED retrofit was performed to assess the financial feasibility of upgrading the existing lighting system at Satria Residence College. The baseline annual energy consumption of the FL lamps was calculated at 51,464 kWh. In comparison, the simulated LED luminaires configuration showed a reduced annual demand of 33,117 kWh. This corresponds to an annual saving of 18,347 kWh as shown in Table 4.

Table 4. Summary of cost payback analysis.

Parameters	Formula	Value
Annual Energy Saving	$E_{saved} = P \times H$	18,347 kWh
Annual Cost Saving	$C_{saved} = E_{saved} \times 0.365$	RM6696.66
Total Investment Cost	-	RM71800
Payback Period	$\text{Payback} = \frac{71800}{6696.66}$	10.7 years

The total annual cost saving of RM6696.66 using RM0.365 per kWh. In this case, the cost of investment was calculated in terms of the total number of luminaires of the building. According to the lighting plan and the simulation, 718 lamps have to be replaced. Using a lamp-only retrofit method, where FL tubes would be replaced by LED tubes and the existing fittings would remain, it was estimated that RM100 would be the average cost per point.

To sum up, the total investment amounted to RM71800. The capital cost was divided by the savings per year using the simple payback formula. The payback period of 10.7 years might seem quite high in comparison with the commercial consideration, since shorter returns are a common priority. Nevertheless, in the case of institutional structures like student residences, this duration is viewed as reasonable since the building has a very long life of operation. After reaching the payback point, the retrofit will still produce continuous financial savings and, in the process, it will minimize the energy demand. This renders the investment financially sustainable and strategically oriented towards the smart campus vision of UTeM and its overall sustainability objectives.

4. Conclusion

To sum up, this paper has explored the possibility of retrofitting FL lighting with LED luminaires to enhance energy consumption and comfort of the residents at Satria Residence College, UTeM. The initial objective was fulfilled by applying to DIALux Evo a close evaluation of the present FL layout, which gave a distinct idea of the current energy consumption and lighting performance. The second objective was the replacement of the baseline system with LED luminaires in the simulation setting, which enabled a comparison of them directly in the same conditions. The findings revealed that it is possible to reduce energy use significantly, retaining adequate levels of illumination and adhering to the applicable standards. Finally, the research was achieved by suggesting a new LED-based design that offers a viable and sustainable solution to institutional houses. In general, the results confirm that LED retrofitting is a powerful concept in terms of minimizing energy consumption, decreasing the overall expenses on operations, and ensuring the quality of lighting in residential buildings. The research also aligns with the project of a smart campus in UTeM and the wider interests related to sustainability, specifically Sustainable Development Goals 7 (Affordable and Clean Energy) and

Goals 12 (Responsible Consumption and Production).

Acknowledgements

The authors would like to express sincere appreciation to the Center for Research and Innovation Management (CRIM) at Universiti Teknikal Malaysia Melaka (UTeM) for the valuable funding support provided for this research. This research is fully funded under Grant No. PJP/2024/FTKE/PERINTIS/SA0010.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Soheilian, M., Fischl, G. and Aries, M. (2021) Smart Lighting Application for Energy Saving and User Well-Being in the Residential Environment. *Sustainability*, **13**, Article 6198. <https://doi.org/10.3390/su13116198>
- [2] Zheng, C., Xu, W., Wang, L., Cao, X., Li, M. and Zhang, A. (2024) Multi-Objective Optimization of Energy, Thermal and Visual Comfort for Dormitory Buildings in the Cold Climate of China. *Indoor and Built Environment*, **33**, 250-268. <https://doi.org/10.1177/1420326x231194314>
- [3] Wagiman, K.R., Abdullah, M.N., Hassan, M.Y., Mohammad Radzi, N.H., Abu Bakar, A.H. and Kwang, T.C. (2020) Lighting System Control Techniques in Commercial Buildings: Current Trends and Future Directions. *Journal of Building Engineering*, **31**, Article 101342. <https://doi.org/10.1016/j.jobe.2020.101342>
- [4] Martirano, L. (2011) A Smart Lighting Control to Save Energy. *Proceedings of the 6th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems*, Prague, 15-17 September 2011, 132-138. <https://doi.org/10.1109/idaacs.2011.6072726>
- [5] Cumo, F., Pennacchia, E. and Sferra, A.S. (2025) Sustainability in Public Lighting: The Methodology for Identifying Environmentally Optimal Solutions in Replacement Planning—A Case Study. *Energies*, **18**, Article 535. <https://doi.org/10.3390/en18030535>
- [6] Fantozzi, F., Le Bail, L., Leccese, F., Rocca, M. and Salvadori, G. (2017) General Lighting in Offices Building: Techno-Economic Considerations on the Fluorescent Tubes Replacement with LED Tubes. *International Journal of Engineering and Technology Innovation*, **7**, 143-156.
- [7] Uydur, C.C. (2022) Comparison of LED and Fluorescent Lamps in Terms of Energy Efficiency: Vocational School Case Study. *1st International Conference on Innovative Academic Studies ICIAS 2022*, Konya, 10-13 September 2022, 6.
- [8] Ma, L. (2024) Smart LED Lighting Systems: Integration of Internet of Things Technology and Energy Saving Potential. *Journal of Progress in Engineering and Physical Science*, **3**, 105-114. <https://doi.org/10.56397/jpeps.2024.12.14>
- [9] Universiti Teknikal Malaysia Melaka (2024) Detailed Energy Audit for Satria Residence College. UTeM.
- [10] Gentile, N. (2022) Improving Lighting Energy Efficiency through User Response. *Energy and Buildings*, **263**, Article 112022. <https://doi.org/10.1016/j.enbuild.2022.112022>
- [11] Lakhier, M.T., Sanmargaraja, S., Olanrewaju, A., Lim, C.H., Ponniah, V. and Math-

- alamuthu, A.D. (2025) Assessing Energy Efficiency in Conventional Office Buildings through Retrofitting Strategies. *Engineering, Technology & Applied Science Research*, **15**, 23197-23203. <https://doi.org/10.48084/etatr.9916>
- [12] Olatunde, T. (2024) A Comprehensive Review of Energy-Efficient Lighting Technologies and Trends.
- [13] Saputri, F.R. and Radithya, L.G. (2024) Simulation Training Using Dialux Evo Software for Estimation of Visual Comfort Level of a Building. *I-Comm: Indonesian Community Journal*, **4**, 581-589. <https://doi.org/10.33379/icom.v4i2.4099>
- [14] Birkha Mohd Ali, S., Hasanuzzaman, M., Rahim, N.A., Mamun, M.A.A. and Obaidelal, U.H. (2021) Analysis of Energy Consumption and Potential Energy Savings of an Institutional Building in Malaysia. *Alexandria Engineering Journal*, **60**, 805-820. <https://doi.org/10.1016/j.aej.2020.10.010>
- [15] Wagiman, K.R., Abdullah, M.N., Hassan, M.Y. and Mohammad Radzi, N.H. (2021) A New Metric for Optimal Visual Comfort and Energy Efficiency of Building Lighting System Considering Daylight Using Multi-Objective Particle Swarm Optimization. *Journal of Building Engineering*, **43**, Article 102525. <https://doi.org/10.1016/j.jobe.2021.102525>
- [16] Witzel, D. (2012) DIALux evo—New Calculation Method. https://www.dial.de/fileadmin/documents/dialux/DIALux_downloads/DIALux_evo_-_New_calculation_method.pdf
- [17] Maulana, A.I. and Kusuma, Y. (2022) Analysis of Natural Lighting and Visual Comfort Multipurpose Hall Building Using Software Dialux Evo 10.0 Case Study: Multipurpose Hall Building of Imbanagara Raya Ciamis Village Chief's Office, West Java. *IOP Conference Series: Earth and Environmental Science*, **1058**, Article 012013. <https://doi.org/10.1088/1755-1315/1058/1/012013>
- [18] Rahmah, L. and Jurizat, A. (2022) The Effect of Window Orientation on the Amount of Light in the Inner Space over Year Using Dialux Evo Application Simulation. *IOP Conference Series: Earth and Environmental Science*, **1058**, Article 012001. <https://doi.org/10.1088/1755-1315/1058/1/012001>
- [19] Malaysian Standard (2014) Malaysian Standard 1525:2014 Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings Code of Practice. Malaysian Standard.
- [20] Coyne, B. and Denny, E. (2021) Retrofit Effectiveness: Evidence from a Nationwide Residential Energy Efficiency Programme. *Energy Policy*, **159**, Article 112576. <https://doi.org/10.1016/j.enpol.2021.112576>
- [21] Hangga, A., Nisa, A.M., Apriliyanto, M., Afandi, M., Pratama, D., Aziz, M.A., *et al.* (2022) Modelling of Lighting System Utilizing Natural and Artificial Lighting Using DIALux. *IOP Conference Series: Earth and Environmental Science*, **969**, Article 012024. <https://doi.org/10.1088/1755-1315/969/1/012024>
- [22] Mahlia, T.M.I., Razak, H.A. and Nursahida, M.A. (2011) Life Cycle Cost Analysis and Payback Period of Lighting Retrofit at the University of Malaya. *Renewable and Sustainable Energy Reviews*, **15**, 1125-1132. <https://doi.org/10.1016/j.rser.2010.10.014>
- [23] European Committee for Standardization (2019) Light and Lighting—Lighting of Work Places—Part 1: Indoor Work Places. prEN 12464-1 Draft. EN Standard.
- [24] Mohammadrezaei, E., Ghasemi, S., Dongre, P., Gračanin, D. and Zhang, H. (2024) Systematic Review of Extended Reality for Smart Built Environments Lighting Design Simulations. *IEEE Access*, **12**, 17058-17089. <https://doi.org/10.1109/access.2024.3359167>