EVOLUTION IN ELECTRICAL AND ELECTRONIC ENGINEERING
e-ISSN: 2756-8458

EEEE

Vol. 5 No. 1 (2024) 204-212
https://publisher.uthm.edu.my/periodicals/index.php/eeee

Analysis of a Classroom Design with an Energy Efficiency Lighting System

Nur Izzati Omar[1], Nor Akmal Jamail[1]*, Qamarul EzaniKamarudin[2]

[1] *Faculty of Electrical and Electronic Engineering,*
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA
[2] *Faculty of Mechanical and Manufacturing Engineering,*
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author: norakmal@uthm.edu.my
DOI: https://doi.org/10.30880/eeee.2024.05.01.026

Article Info

Received: 2 July 2023
Accepted: 3 September 2024
Available online: 30 April 2024

Keywords

Classroom Design, Lighting, DIALux Evo, Energy Efficiency

Abstract

Classroom design plays a crucial role in creating optimal learning environments for students. Traditional lighting systems, such as fluorescent lamps, can be less efficient and negatively affect student performance and health. To address this issue, a case study was conducted in a seminar room at University Tun Hussein Onn Malaysia (UTHM). The DIALux Evo software was used to validate outcomes and replicate the illumination setting. The work involves modeling the classroom space selected appropriate lighting fixtures, and configured the lighting system to meet recommended illumination standards while optimizing energy consumption. Clean energy could lower electricity costs, reduce the environmental impact of fluorescent lighting, and promote sustainable growth. This case study's main goal is to figure out the classroom's minimum lamp based on the standard illuminance level and design an energy-efficient lighting system with sustainable practices. Following the implementation of the lighting retrofit, the revised lighting configuration has the potential to conserve up to 305.28 kWh or 72.60% of energy monthly. Future research could use more models of luminaires to facilitate more lucid and precise contrasting elements and to enhance the research, it is recommended to obtain more comprehensive data of energy consumption patterns, architectural lighting design, and electrical load of the classroom. Energy-efficient lighting in classrooms improves student outcomes and reduces energy consumption educational institutions should adopt energy-efficient lighting systems to improve student outcomes, reduce energy consumption, and contribute to a more sustainable future.

1. Introduction

Due to population growth, Malaysia is using a lot of fossil fuels to generate power [1]. In 2019, energy consumption was 66,483 ktoe (thousand ton of oil equivalent) and electricity consumption was 158,603 GWh, up 2.8% and 3.8%, respectively. The industrial sector consumed 49.4% of Malaysia's electricity, 78,427 GWh. Residential use consumed 21.0% of electricity, while commercial use consumed 28.8% [2]. Buildings use lots of energy. Artificial lighting consumes a lot of electricity in the 21st century. Energy-efficient lighting methods are valuable given the rise in energy consumption by various market sectors and the difficulty of generation [3]. Buildings in educational institutions also contribute to energy consumption. Students had access to a learning environment in classrooms ranging from elementary schools to universities. Lighting in university classrooms is crucial to academic development [4].

Classroom lighting is crucial to a productive learning environment since students spend most of their time there. Lighting affects students' moods and learning. Long-term exposure to low-quality illumination is also detrimental to students' concentration and academic performance [5]. Thus, good lighting reduces fatigue and boosts worker, employee, and student productivity [6]. As one of the electrical loads, lighting will contribute to energy consumption. Heating, ventilation, air conditioning (HVAC), and lighting have increased building energy consumption in recent years. Significant efforts have been made to reduce energy demand through energy-efficient design in response to the consistently rising demand.

The location of the case study Bilik Seminar 2 was selected from one of University Tun Hussein Onn Malaysia's (UTHM) block G1 electrical and electronic engineering faculty classrooms. FKEE G1 contributes to UTHM's high monthly energy consumption through 2020 among UTHM's buildings [7]. Improving a building's lighting is one of the most cost-effective ways to boost energy efficiency [8]. The field visit found a fluorescent lamp in the classroom, which is less energy-efficient than an LED lamp. Inefficient lighting systems use more energy to produce the same lighting quality, increasing electricity costs. Installing more lamps to produce the same energy increases the cost.

Frequent switching contributes to the deterioration of lamps, which is one of the disadvantages of fluorescent lighting. Several of the classroom's lamps are broken. There appear to be more costs associated with maintenance. If this continues, students must study in poor lighting, which can cause eye diseases. Fluorescent lamp UV radiation has caused cataracts and pterygium [9]. Thus, this case study's aim is to create an energy-efficient lighting system using DIALux Evo software that reduces energy use and promotes long-term sustainability. Consequently, replacing standard fluorescent lighting with more energy-efficient technology saves energy, money, and the environment. Switching to clean energy could reduce electricity costs further, lessen the environmental impact of fluorescent lighting and electricity generation from fossil fuels, and promote sustainable growth.

2. Materials and Methods

This section discusses the methods that can be used to design an efficient lighting system to be used in the Bilik Seminar 2. In addition, this section presents a comprehensive method for the work as well as detailed procedures, all of which are explained in the following subsections.

2.1 Materials

The materials for the work are consisted of data collection, lighting retrofit procedure and illuminance standard level.

- *Data Collection*

  A comprehensive collection of data of the architectural aspects of the classroom, the electrical load associated with the lighting system, and the arrangement of lighting system has been diligently acquired in anticipation of the forthcoming design process. The utilisation of this data will be imperative for its later integration into the design process. For this case study, a seminar room in Block G1 of the University Tun Hussein Onn Malaysia's (UTHM) Faculty of Electric and Electronic Engineering (FKEE) was selected. Parit Raja, Batu Pahat District, Johor, Malaysia (1.8598459125313882, 103.08851972792277) was the location of the case study.

Fig. 1 *Location of G1 Faculty of Electrical and Electronic Engineering from Google Earth*

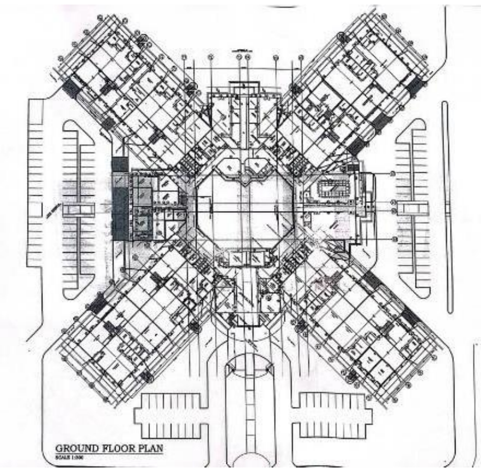

Fig. 2 *Floor plan of G1 Faculty of Electrical and Electronic Engineering*

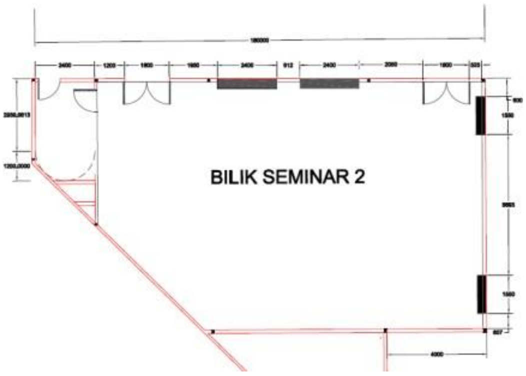

Fig. 3 *Floor plan of the classroom drawn in AutoCAD*

Fig. 1 depicts the FKEE G1's position on Google Maps. Observation revealed that the classroom was located on the ground floor and was equipped with electronic devices such as an LCD projector, a loudspeaker, and a power mixer. Fig. 2 and Fig. 3 depict the floor plan of the ground floor of the FKEE G1 and the floor plan of the classroom drawn in AutoCAD.

- *Lighting Retrofit Procedure*
  The lighting retrofit procedure is first, to figure out the room's dimensions, working plane height, wall, and ceiling colour, lamp types, and lighting system configuration. Based on the standard illuminance, the classroom's minimum number of lamps was calculated. After manual calculations, DIALux simulates and evaluates the classroom's lighting environment and lamp count.
- *Illuminance Standard Level*
  The consideration of illuminance criteria is essential to achieve a well-designed lighting system. The level and distribution of illumination have a notable impact on an individual's perception and completion of visual tasks in terms of speed, accuracy, and comfort [10]. The illuminances that are provided should be in line with the recommendations presented in Table 1, which outlines the proper room illumination levels for general building areas [11].

Table 1 *Room Illumination level recommended by IES, MS1525, and JKR*

General Building Areas	Room Illumination Level (lux)		
Further education establishment	IES Standards	MS 1525	JKR
Lecture theatre general	500	300-500	300
Demonstration benches	500	300-500	300
Examination halls, seminar room, teaching spaces	500	300-500	300
Laboratories	500	300-500	300
Workshop	300	300-500	300

Hence, the suggested amount of illuminance for a seminar room was determined to be between 300- 500 lux. The level of illuminance has been observed to have a positive impact on the productivity of students, which in turn is reflected in their academic performance.

2.2 Methods

The lighting retrofitting technique is visually represented in Fig. 4 through the utilisation of a flowchart. To proceed with the analysis and design of the room's lighting system, it is imperative to ascertain several key parameters. These parameters include the dimensions of the room, namely its length, width, and height, as well as the height of the working plane. Additionally, it is crucial to consider the colour of the walls and ceiling, the types of lamps to be employed, and the configuration of the lighting system. By thoroughly examining and understanding these fundamental aspects, a comprehensive and effective lighting solution can be devised.

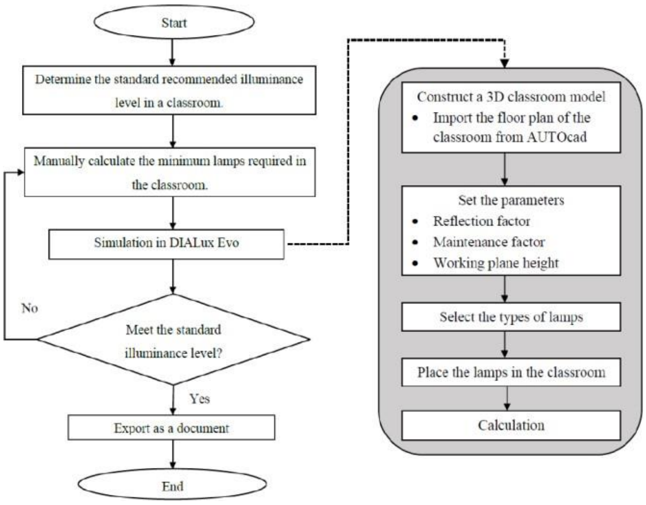

Fig. 4 *Flowchart of the lighting retrofit procedure and the simulation in DIALux Evo software*

2.3 Equations

The manual approach encompasses three distinct sub-methods, namely point-to-point, watts per square meter, and lumen. The Lumen method is widely favored among the three methods due to its high level of accuracy and straightforwardness [12]. The approach employs horizontal illuminance criteria to show a consistent arrangement of luminaires. The lumen method involves the division of the total lumens present in a given space by the corresponding area of that space [13]. Computation necessitates the consideration of numerous factors, coefficients, lamp lumen data, and various other quantities. The equations utilised in the lumen method show imprecision and make certain assumptions [14]. The calculation for figuring out the minimum number of lamps is derived from equation (1).

$$N = \frac{E\ (lx\ required) \times Area(m^2)}{lumen\ from\ each\ luminaire\ \times UF\ \times MF} \quad (1)$$

Lighting calculations must use the Maintenance Factor (MF) to account for gradual illumination reduction. Dirty fittings reduce luminous flux. A lighting installation emits 80% of the light it would if it were spotless, according to conventional wisdom. In this design, MF was 0.8. Following the table's lamp quantity, the luminaires should be arranged according to design principles.

$$EC = E_M \times tariff\ rate \quad (2)$$

Analysing and comparing simulation results concluded this work. Light retrofitting required comparing pre- and post-retrofitting energy consumption. Next, energy and cost savings were estimated. Retrofitted models' energy consumption was compared. To approximate the amount of cost savings, the cost of electricity was estimated using equation (2) which was based on TNB tariff rates as shown in Fig. 5.

Tariff Category	Unit	Existing Rates (1 June 2011)	New Rates (1 January 2014)
1. Tariff A – Domestic Tariff			
For the first 200 kWh (1 - 200 kWh) per month	sen/kWh	21.80	
For the next 100 kWh (201 – 300 kWh) per month	sen/kWh	33.40	
For the next 100 kWh (301 – 400 kWh) per month	sen/kWh	40.00	
For the next 100 kWh (401-500 kWh) per month	sen/kWh	40.20	
For the next 100 kWh (501-600 kWh) per month	sen/kWh	41.60	
For the next 100 kWh (601-700 kWh) per month	sen/kWh	42.60	
For the next 100 kWh (701-800 kWh) per month	sen/kWh	43.70	
For the next 100 kWh (801-900 kWh) per month	sen/kWh	45.30	
For the next kWh (901 kWh onwards) per month	sen/kWh	45.40	
The Minimum Monthly Charge is	*RM*	*3.00*	
New Structure			
For the first 200 kWh (1 - 200 kWh) per month	sen/kWh		21.80
For the next 100 kWh (201 – 300 kWh) per month	sen/kWh		33.40
For the next 300 kWh (301 – 600 kWh) per month	sen/kWh		51.60
For the next 300 kWh (601 – 900 kWh) per month	sen/kWh		54.60
For the next kWh (901 kWh onwards) per month	sen/kWh		57.10
The Minimum Monthly Charge is	*RM*		*3.00*

Fig. 5 *TNB tariff rates*

A comparison was made between the energy consumption of models before and after retrofitting. Consequently, the estimation of energy and cost savings was conducted using equation (3). In the end, the results of the analysis were documented and presented. According to Section 26 of the Electricity Supply Actof 1990, the Minister of Energy, Water, and Communications has approved the tariff that takes effect on June 1st, 2006, as shown in Fig. 5[15].

$$Saving\% = \left| \frac{before - after}{before} \right| \times 100 \quad (3)$$

3. Results and Discussion

A comprehensive study was conducted as part of this work, and the results were obtained. The purpose of this study is to investigate energy-saving opportunities in classroom lighting systems. Installation of a lighting system allows further reductions in energy consumption. This study's findings and discussion have been divided into multiple segments. The results of the lighting system design and simulation of the lighting environment using the DIALux Evo software are presented. In addition, this section examines the energy and cost savings resulting from the implementation of a lighting retrofit. This section also provides analysis and estimation of the production and cost of energy and electricity.

3.1 Lighting Retrofit

The energy required to provide adequate lighting in the classroom can be decreased and the quality of the lighting provided can be improved by retrofitting older lighting systems with luminaires that are more energy-efficient [16]. With the intention of reducing the classroom's energy usage and ensuring that the lighting levels meet the requirements for learning environments, a lighting retrofit was put into place. DIALux Evo software was used to build a classroom model that accurately reflected the lighting conditions found in a typical classroom. Two distinct scenarios—one for the pre-retrofitting model and the other for the post-retrofitting model were used to display and compare the simulation results.

- *Simulation and analysis before retrofitting*
  Using the DIALux evo simulation software, the following section shows the simulation results of the classroom model prior to retrofitting. As depicted in Fig. 6, the architectural data of the classroom was acquired beforehand, and then the first classroom model was replicated using the simulation software DIALux evo. Presently, there are 30 recessed fluorescent lamps and 16 compact fluorescent lamps installed in the ceiling of the classroom. Table 2 shows a summary of the simulation outcomes, which are based on the working plane level.

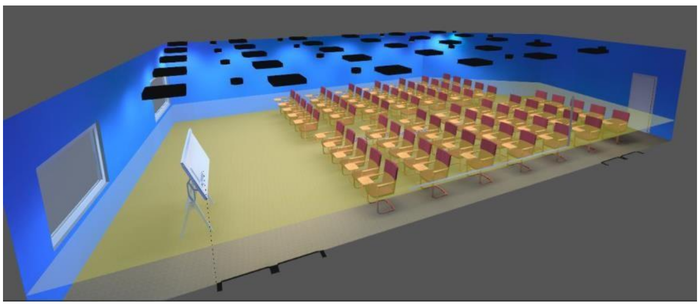

Fig. 6 *The Bilik Seminar 2 lighting model and its lighting arrangement*

Table 2 *The summary of the simulation of the results in DIALux Evo*

Lamp Type	Number of luminaires	Power of each luminaire (W)	Average illuminance level (lux)
Ceiling recessed fluorescent lamp	30	78	622
Compact fluorescent lamp	16	18	

As stated previously, the recommended illumination level for this case study's location, a seminar room, was between 300 and 500 lux. According to Table 2, the average level of illumination in the Bilik Seminar 2 model before retrofitting was 622 lux. As a result, it was decided that the seminar room's illumination level exceeded its standard values, showing a waste of illumination level and electrical energy.

- *Simulation and analysis after retrofitting*

  Because LED is a highly energy-efficient lighting technology that has the potential to fundamentally alter the future of lighting globally and uses less electricity to produce the same amount of light, it was selected as the primary retrofitting choice for this work. To find the optimal lamps for retrofitting, a variety of lamps with varying wattages (38W-40W) and characteristics were selected. The simulation of these lamps was then performed using the DIALux evo software. Table 3 provides a comparison of the characteristics of three selected LED lamps. Lamp model 2 showed the highest luminous efficacy of 147.5 lm/W, while lamp 3 showed the lowest luminous efficacy of 90 lm/W, according to the data presented in Table 3.

Table 3 *Characteristics of selected LED lamps model*

Lamp No.	Lamps	Lamp Type	Power (W)	Lamp Flux (lm)	Luminous efficiency (%)	Luminous efficacy (lm/W)	CCT (K)	CRI
1	ABRFB-R1X145/45DA-SM-550M840 0660004	LED	40	4960	82	123	4000	80
2	LOG 50 OFFICE SD WALL/CEILING 716-0104150414500	LED	40	5900	100	147.5	4000	80
3	L 600 35W/940 DALI EP VSS 621X621 22908	LED	40	3587	100	90	4000	90

In addition, the number of lamps was determined using the lumen method in Equation 1 and validated by DIALux evo based on the recommended luminance level. Table 4 compares the simulation results of four testing models with four LED lamps chosen based on the level of the working plan. According to the table below, there were no statistically significant differences between the average brightness levels of the four models because they all met the minimum standard. Model 3 required the most lamps to be put up in the classroom and used the most power overall, with 32 lamps and 2,560 W, respectively. Model 2 needed the least amount of power, 720 W, and the fewest number of lamps, 18. Lamp 2 was the best choice for retrofitting because it has the least total power

Table 4 *Summary of DIALux Evo results of the model based on the working plane level*

Model No.	Number of Lamps	Power per lamp (W)	Total power (W)	Average illuminance level (lx)	Luminous efficacy (lm/W)
1	22	40	880	512	122.7
2	18	40	720	541	147.5
3	32	40	2560	514	89.7

The outcomes for the three models are presented in a bar chart format, as shown in Fig. 7. In general, it can be concluded that a light source with a higher luminous efficacy requires fewer number of luminaries to reach the same level of illuminance, resulting in reduced total power consumption.

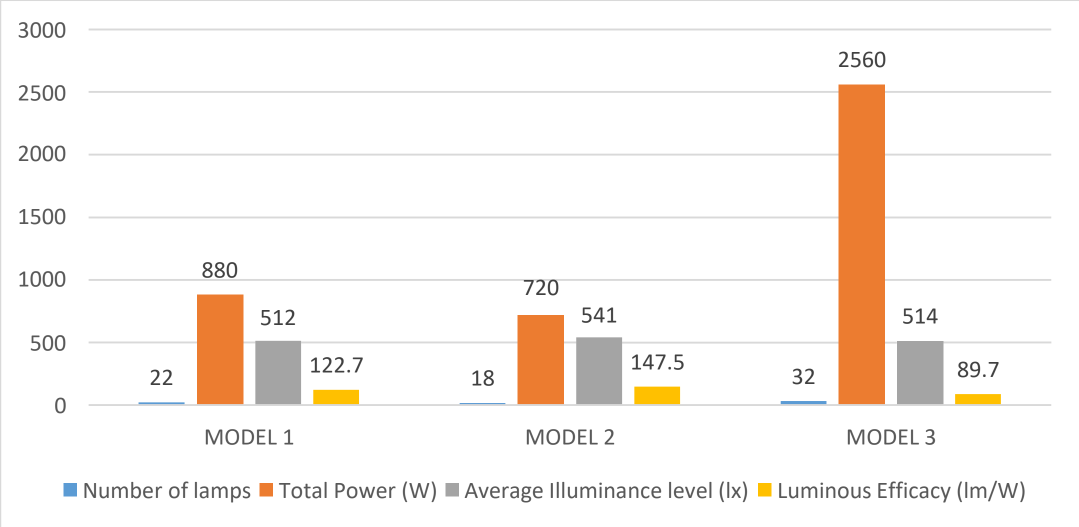

Fig. 7 *Bar chart of the results from the three model lamps*

- *Energy Reduction*

  In Table 5, the energy consumption of the model before and after retrofitting is compared. Based on the data in the table, the model before retrofitting used 420.48 kWh of energy per month, while the model after retrofitting only used 115.2 kWh per month. Upon comparing the outcomes, it was discovered that the retrofitted model showed a significant decrease in energy consumption of 72.60 percent. This finding shows that the lamp's characteristics were significantly related to the amount of energy saved by retrofitting lighting.

Table 5 *Comparison of energy estimation before and after retrofitting*

Model	Total power (w)	Hour's usage (h)	Day	Week	Total energy usage per month (kWh)
Before retrofitting	2628	8	5	4	420.48
After retrofitting	720	8	5	4	115.20
				Saving (kWh)	**305.28**
				Saving (%)	**72.60**

Table 6 compares the expected reduction in electricity expenses for the model, both before and after retrofitting. Before the retrofitting, the cost of electricity for the model was RM 138.92 per month and RM 1667.04 per year. Since then, the retrofitted model had a monthly electricity cost of RM 33.83 and an annual electricity cost of RM 405.96. Because of this, the lighting upgrade in the case study led to an annual decrease in electricity costs of RM 1261.08, or 75.65%.

Table 6 *Electricity cost-saving estimation*

Model	Total energy usage per month (kWh)	Monthly electricity cost (RM)	Annual electricity cost (RM)
Before retrofitting	420.48	138.92	1667.04
After retrofitting	115.20	33.83	405.96
		Saving (RM)	**1261.08**
		Saving (%)	**75.65**

3.2 Summary

Table 7 *Summary of overall results*

Model	Energy Saving (%)	Cost Saving (%)
After lighting retrofitting	72.60	75.65

Table 7 displays a summary of the outcome. In summary, the newly implemented lighting design resulted in a reduction in energy consumption by 72.60% and a decrease in costs by 75.65%. There was a correlation observed between the characteristics of the lamp and its energy efficiency.

4. Conclusion

The study conducted a comprehensive selection process to identify the ideal LED lamp to replace the current fluorescent lamps in the classroom. The chosen LED lamp was determined based on energy efficiency criteria. The optimal number of lamps required for the classroom was determined using the lumen method and verified using DIALux evo software, ensuring the illumination quality remained uncompromised. The research focused on evaluating the effects of the lighting retrofit on energy consumption within the given setting. The study analyzed the monthly energy reduction achieved through the implementation of the new lighting design and estimated cost savings. The results showed a significant decrease in energy consumption, with a monthly reduction of 305.28 kWh or 72.60%. The estimated electricity cost savings amounted to RM 968.64 annually, equivalent to a cost reduction of 84.02%.

In conclusion, this case study on the energy-efficient lighting system in UTHM's Bilik Seminar 2 provides valuable insights into the establishment of an energy-efficient lighting environment in educational settings. The results highlight a significant decrease in energy consumption and substantial cost savings achieved through the implementation of an energy-efficient lighting design. Based on the findings, it is recommended that educational institutions prioritize energy-efficient lighting systems to reduce energy consumption and costs. Future research should focus on gathering more accurate data on energy demand, developing detailed architectural lighting plans, and obtaining specific electrical load information to further enhance understanding and implementation of energy-efficient lighting systems in educational environments.

Acknowledgement

The authors would like to express the deepest gratitude to the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support. The authors would also like to extend the appreciation to each and every individual for the assistance and contribution offered throughout the execution of the entire work.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

[1] "Renewable Energy In Malaysia: The Future Is Here." https://pitech.com.my/renewable-energy- in-malaysia/ (accessed Nov. 10, 2022).
[2] Suruhanjaya Tenaga (Energy Commission), "Neraca Energi Nasional 2019 - National Energy Balance 2019," p. 84, 2022, [Online]. Available: https://www.den.go.id/index.php/publikasi
[3] A. Sholanke, O. Fadesere, and D. Elendu, "The Role of Artificial Lighting in Architectural Design: A Literature Review," *IOP Conf Ser Earth Environ Sci*, vol. 665, no. 1, 2021, doi: 10.1088/1755-1315/665/1/012008.
[4] A. Hidalgo, L. Villacrés, R. Hechavarría, and D. Moya, "Proposed integration of a photovoltaic solar energy system and energy efficient technologies in the lighting system of the UTA- Ecuador," *Energy Procedia*, vol. 134, pp. 296–305, Oct. 2017, doi: 10.1016/J.EGYPRO.2017.09.529.
[5] P. Singh and R. Arora, "Classroom Illuminance: Its impact on Students' Health Exposure & Concentration Performance," 2014.
[6] M. O. Oyeleye, "Illumination Evaluation of Lecture Theatre, Case Study of 1000 Seat Lecture Theatre, Federal University of Technology, Akure, Nigeria," *European Journal of Engineering Research and Science*, vol. 4, no. 7, pp. 31–36, Jul. 2019, doi: 10.24018/ejers.2019.4.7.1420.
[7] "Energy Consumption 2020 – Sustainable Campus Office." https://scu.uthm.edu.my/uthm- energy-usage-2020/ (accessed Jan. 15, 2023).
[8] "I N T E R N AT I O N A L E N E R G Y A G E N C Y ENERGY EFFICIENCY POLICY PROFILES LIGHT'S LABOUR'S LOST Policies for Energy-efficient Lighting." [Online]. Available: http://www.iea.org/w/
[9] "Eye Disease Resulting From Increased Use of Fluorescent Lighting as a Climate Change Mitigation Strategy," 2011, doi: 10.2105/AJPH.
[10] "JKR STANDARD JKR/SIRIM X:2021 Indoor environmental quality (IEQ) for office buildings," 2021. [Online]. Available: http://www.sirimsts.my
[11] "ROOM ILLUMINATION LEVEL."
[12] Chartered Institution of Building Services Engineers., *Electricity in buildings.*

[13] "LightCalc Lighting Software Glossary." https://web.archive.org/web/20080316005415/http:/www.lightcalc.com/glossary.html (accessed Jan. 22, 2023).
[14] D. Tawfeeq Alzuhairi, "Electrical Installation Lecture No.11 Lighting design and calculations THE LUMEN METHOD."
[15] TNB, "Tariff_Rate_Final_01.Jan.2014".
[16] S. Gorgulu and S. Kocabey, "An energy saving potential analysis of lighting retrofit scenarios in outdoor lighting systems: A case study for a university campus," *J Clean Prod*, vol. 260, p. 121060, Jul. 2020, doi: 10.1016/J.JCLEPRO.2020.121060.