Illuminance study of lecture rooms and laboratories in an educational academic building based on the MS 1525 standard

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ABSTRACT

The lighting system is a crucial system in classrooms and other educational facilities such as laboratories and sports centers. Poor lighting conditions will affect the ability of the students to see clearly during classes and result in eye strain, fatigue, headache, and stress. Hence, this study aims to investigate the illuminance levels in four lecture rooms and six laboratories in the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia using DIALux evo 10.0 lighting design software. The illuminance levels determined from simulations were compared with the required illuminance levels for classrooms (300 lx) and laboratories (500 lx) stipulated in the Malaysian standards (MS) 1525-energy efficiency and use of renewable energy for non-residential buildings. Based on the results, the selected lecture rooms were overlit, whereas three of the laboratories were underlit. Suggestions were made to improve the illuminance levels of the lecture rooms and laboratories by changing the specifications of the lighting system or by making use of natural sunlight from the windows.

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1. INTRODUCTION

Lighting technology has shown remarkable improvements over the years. Lighting systems are an essential element of buildings in order to perform daily tasks and activities. Educational facilities such as lecture rooms, lecture halls, and laboratories require good lighting systems because the illuminance levels will significantly influence the teaching and learning environment as well as energy management [1], [2]. Hence, there is a critical need to improve lighting systems in educational facilities. Since the design and layout of educational facilities significantly influence the choice of the lighting system, it is necessary to identify key design issues and future trends in educational facilities [3]–[5]. In Malaysia, the specifications for lighting systems are stipulated in the Malaysian standards (MS) 1525-energy efficiency and use of renewable energy for non-residential buildings. The lighting system needs to provide a suitable environment in order to perform a variety of tasks and enhance the appearance of objects [6], [7]. It is crucial to improve the lighting systems in educational facilities in order to enhance the teaching and learning environment and promote visual acuity [8], [9]. A well-designed lighting system makes the atmosphere in educational facilities more appealing and enjoyable, reinforces perceptions of spaciousness, stimulates teaching and learning, and improves work productivity. Daylighting involves making effective use of apertures such as windows and skylights to maximize the use of natural sunlight in order to illuminate building interiors, which can enhance the tone and appearance of objects [10]. In educational facilities, daylighting can be achieved by opening window blinds and roller shades, which can affect the illuminance levels in the educational facilities. However, over lighting resulting from the lighting system and natural sunlight from windows can cause glare, resulting in eye strain, fatigue, headache, stress, and loss of concentration. A light-emitting diode (LED) is a semiconductor device that emits light when an electric current flows through it. When current flows through an LED, the electrons recombine with holes emitting light in the process. LEDs are electrical devices that create a small amount of light by allowing energy to pass through them in one direction [11]. An electrical current pass through a microchip, which illuminates the LEDs and produces visible light. The use of LEDs can reduce energy consumption by 30-50% for lighting and 10-20% for cooling [12]. LED luminaires can be considered replacements for conventional lighting systems if the luminous efficiency, lighting distribution on the illuminated area, and color quality are superior to those of conventional lighting systems [13]. Luminous flux is the energy of the light emitted per second in all directions [14]. The unit of luminous flux is lumen (lm). One lumen is defined as the luminous flux of light produced by a light source that emits 1 candela (cd) of luminous intensity over a solid angle of 1 steradian (sr) [15]. To improve visual comfort in educational facilities, it is essential to determine their illuminance levels and ensure that the illuminance levels are within those prescribed by standards. Illuminance is a measure of the amount of light falling onto and spreading over a given surface area [16]. The illuminance can be determined using (1) [17], [18].

$$E_v = \frac{n \times F \times UF \times MF}{A} \quad (1)$$

Where E_v is the illuminance (lx), F is the initial lamp output (lm), n is the number of lamps per luminaire, UF is the utilization factor, MF is the maintenance factor, and A is the room area (m^2). The utilization factor is defined as the lumens received on the working plane divided by the lumen output of the luminaires, and accounts for the loss of light due to absorption on the room surfaces. The maintenance factor indicates how lighting conditions are affected by the daily use of luminaires, and is defined as the product of the room surface maintenance factor (dirt on the room surfaces), luminaire maintenance factor (dirt on the luminaires), lamp lumen maintenance factor (dirt on the lamps), and luminaire survival factor (reduced light output due aging and failure of the lamps). The correlated color temperature is a measure of the color appearance of the light emitted by a light source, where the color of the light source is related to the color of light of a reference light source when heated to a particular temperature, measured in degrees Kelvin (K) [19]. In simple terms, the correlated color temperature represents the warmness or coolness of a light source. Most of the fluorescent lamps used in academic buildings have a correlated color temperature of 3,000, 4,000, and 5,000 K. In warm regions, a cooler color appearance is preferred, which can be achieved by using lamps with a correlated color temperature of above 5,000 K. In contrast, a warmer color appearance is preferred in colder regions, and this can be achieved by using lamps with a correlated color temperature of less than 4,000 K [20]. The color rendering index is a measure of the ability of an artificial white light source (e.g., LEDs and fluorescent lamps) to accurately reproduce the colors of objects illuminated by it compared with natural daylight, and it is measured on a scale of 0-100. A high color rendering index (90-100) indicates that the light source has excellent color rendering characteristics and that the objects illuminated by the light source appear natural. In contrast, a low color rendering index (<80) indicates that the light source has poor color rendering characteristics, and the objects illuminated by the light source appear distorted in terms of their color appearance [21]. Owing to the importance of improving lighting systems in educational facilities, this study aims to investigate the illuminance levels in four lecture rooms and six laboratories in the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia, by simulations. The illuminance levels determined from simulations are then compared with the required illuminance levels for classrooms (300 lx) and laboratories (500 lx) stipulated in the MS 1525 standard in order to determine whether the rooms are overlit, underlit, or adequately lit. It is believed that the findings of this study will be useful to improve the lighting systems in educational facilities.

2. METHODOLOGY

First, a room was selected to validate the illuminance levels predicted by the simulation model developed in DIALux evo 10.0 lighting design software (DIAL GmbH, Germany). The illuminance measurement was performed by using the digital light meter (Model HS 1010) The illuminance measurements were performed by placing the digital light meter on the working plane of the room.

The specifications of the validation room (i.e., lamp type, working plane, number of luminaires, and room dimensions) are summarised in Table 1. Following this, four lecture rooms and six laboratories in the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia, were selected to determine their illuminance levels. The room dimensions were measured, and the positions of the lamps and windows, as well as the arrangement of furniture and equipment in the rooms, were identified. The specifications of the lecture rooms and laboratories selected in this study are summarised in Tables 2 and 3, respectively. The lamp type used in the lecture rooms and laboratories was the same. However, the number of luminaires differed from one room to another due to the difference in the size and capacity of the rooms. The lecture rooms and laboratories were equipped with the same basic furniture such as tables, chairs, and whiteboards. All of the windows inside the lecture rooms and laboratories were installed with blinds to block out sunlight, which could cause glare and lead to a loss of concentration among the students.

Based on the technical measurements of the lecture rooms and laboratories, three-dimensional models of the lecture rooms and laboratories were developed using DIALux evo 10.0 software. This software is used to simulate the illuminance levels of natural and artificial light sources, analyze the annual energy consumption of artificial lighting, evaluate energy savings resulting from daylighting, and assess the energy performance of buildings [22]. The characteristics of the lecture rooms and laboratories such as the room dimensions, number and arrangement of luminaires, color and arrangement of furniture and equipment, installation of blinds at the windows, and paint, were the same as those in the actual lecture rooms and laboratories so that the simulation models were representative of the actual case. The fixtures and furnishings for the simulation models are available in the DIALux evo 10.0 library. Table 4 shows the lighting specifications for the actual and simulation cases. It shall be noted that the Philips Ecofit T8 LED tube was not available in the software, and therefore, the lamp was replaced with an NVC International T8E LED tube having similar specifications [23], [24]. The average illuminance levels predicted by the simulation models were then compared against the required illuminance levels specified in the MS 1525 standard for classrooms and laboratories to determine whether the rooms were overlit, underlit, or adequately lit.

Table 1. Specifications of the validation room

Room code	Lamp type	Working plane (m)	Number of luminaires	Room dimensions (length×width) (m×m)
Validation room	Philips Lifemax fluorescent tube, 36 W	0	1	1.92×1.92

Table 2. Specifications of the lecture rooms

Room code	Lamp type	Working plane (m)	Number of luminaires	Room dimensions (length×width×height) (m×m×m)
BK 1	Philips Ecofit LED tube, 18 W	0.75	16	12.00×7.20×2.60
BK 3	Philips Ecofit LED tube, 18 W	0.75	48	14.57×8.99×3.30
BK 9	Philips Ecofit LED tube, 18 W	0.75	24	8.82×7.33×3.30
BK 10	Philips Ecofit LED tube, 18 W	0.75	36	10.21×5.29×3.30

Table 3. Specifications of the laboratories

Room code	Lamp type	Working plane (m)	Number of luminaires	Room dimensions (length×width×height) (m×m×m)
ME 12	Philips Ecofit LED tube, 18 W	0.90	64	14.84×14.55×3.30
ME 18	Philips Ecofit LED tube, 18 W	0.90	64	15.25×14.34×3.30
ME 1	Philips Ecofit LED tube, 18 W	0.90	64	14.95×14.64×3.30
ME 23	Philips Ecofit LED tube, 18 W	0.90	100	14.95×14.11×3.30
ME 5	Philips Ecofit LED tube, 18 W	0.90	220	33.02×14.34×3.30
ME 7	Philips Ecofit LED tube, 18 W	0.90	220	31.92×14.72×3.30

Table 4. Lighting specifications for the actual and simulation cases

Specification	Actual case	Simulation case
Lamp type	Philips Ecofit T8 LED tube	NVC International T8E LED tube
Luminous flux (lm)	1,800	1,840
Input power (W)	18	18
Color designation	Cool white	Cool white
Correlated color temperature (K)	6,500	6,500
Color rendering index	80	75

3. RESULTS AND DISCUSSION

To validate the accuracy of the simulation model developed in the DIALux evo 10.0 software, the illuminance levels of the validation room were measured and compared with those predicted by the simulation model, and the results are tabulated in Table 5. It can be observed that the illuminance levels predicted by the simulation model showed good agreement with those from measurements, with a percentage error of less than 2%. This is indeed expected since the DIALux evo 10.0 software conforms to the European standard (EN) 12464-1:2011 [25].

Following this, four lecture rooms were simulated using the DIALux evo 10.0 software to determine their illuminance levels, and the average illuminance levels were compared with the illuminance levels required for classrooms (300 lx) and laboratories (500 lx) stipulated in the MS 1525 standard. The percentage differences were calculated for the lecture rooms and laboratories selected in this study to determine whether the rooms were overlit, underlit, or adequately lit. Based on practical experience, the percentage difference between the average illuminance level obtained from simulation and the required illuminance level should be within 20%. The results are presented in Tables 6 and 7.

As shown in Table 6, the average illuminance levels of BK 1, BK 3, BK 9, and BK 10 lecture rooms were significantly higher than the value prescribed in the MS 1525 standard, resulting in percentage differences of more than 20%. Hence, it can be deduced that the lecture rooms were overlit. As shown in Table 7, three laboratories (ME 1, ME 12, and ME 18) did not meet the required illuminance level of 500 lx, and these laboratories were underlit, as indicated by the negative percentage differences. In contrast, the ME 5, ME 7, and ME 23 laboratories met the required illuminance level, with percentage differences of less than 20%, indicating that these laboratories were adequately lit. Simulations were performed to improve the illuminance levels of BK 1, BK 3, BK 9, and BK 10 lecture rooms and ME 1, ME 12, and ME 18 laboratories in order to meet the illuminance level requirements set in the MS 1525 standard. This was done by varying the number of luminaires, changing the lighting arrangement, changing the lamp type, or making use of natural sunlight. Suggestions were made to improve the illuminance levels of the lecture rooms and laboratories, as summarised in Tables 8 and 9. Figure 1 shows the simulation result for the ME 18 laboratory before improvement, whereas Figure 2 shows the simulation result after improvements were made by opening the window blinds to let natural sunlight into the laboratory. Indeed, the average illuminance level increased from 406 lx (Table 7) to 572 lx (Table 9) by making use of natural sunlight.

Table 5. Validation of the simulation model developed in the DIALux evo 10.0 software

Illuminance level obtained from measurements (lx)	Illuminance level obtained from simulations (lx)	Percentage error (%)
180	182	0.55
200	198	0.50
180	176	1.12
190	194	1.04
220	228	1.79
200	194	1.52
180	178	0.56
200	205	1.23
180	180	0.00

Table 6. Comparison between the average illuminance levels predicted by the simulation models and the required illuminance level stipulated in the MS 1525 standard for lecture rooms

Room code	Average illuminance level (lx)	Required illuminance level (lx)	Deviation in illuminance level (lx)	Percentage difference (%)	Remark
BK 1	460	300	160	53.33	Overlit
BK 3	447	300	147	49.00	Overlit
BK 9	365	300	65	21.67	Overlit
BK 10	401	300	101	33.67	Overlit

Table 7. Comparison between the average illuminance levels predicted by the simulation models and the required illuminance level stipulated in the MS 1525 standard for laboratories

Room code	Average illuminance level (lx)	Required illuminance level (lx)	Deviation in illuminance level (lx)	Percentage difference (%)	Remark
ME 12	438	500	−62	−12.40	Underlit
ME 18	406	500	−94	−20.00	Underlit
ME 1	413	500	−87	−17.40	Underlit
ME 23	550	500	50	10.00	Adequately lit
ME 5	576	500	76	15.20	Adequately lit
ME 7	567	500	67	13.4	Within range

Table 8. Suggestions to improve the illuminance levels inside the lecture rooms

Room code	Suggestions	Average illuminance level after improvement (lx)
BK 1	– Because the room height is only 2.6 m from the floor, the distance between the luminaires and a working plane is closer than that in other lecture rooms. – Reduce the number of luminaires from 24 to 12. – Change the lighting arrangement from vertical to horizontal.	346
BK 3	Reduce the number of luminaires from 48 to 32.	324
BK 9	Reduce the number of luminaires from 24 to 16.	318
BK 10	Reduce the number of luminaires from 48 to 32.	303

Table 9. Suggestions to improve the illuminance levels inside the laboratories

Room code	Suggestions	Average illuminance level after improvement (lx)
ME 12	– Make use of natural sunlight by opening the window blinds.	556
	– Change the lamp type. Use lamps with a luminous flux of 2,100 lm instead of those with a luminous flux of 1,800 lm.	505
ME 18	Make use of natural sunlight by opening the window blinds.	572
ME 1	Make use of natural sunlight by opening the window blinds.	553

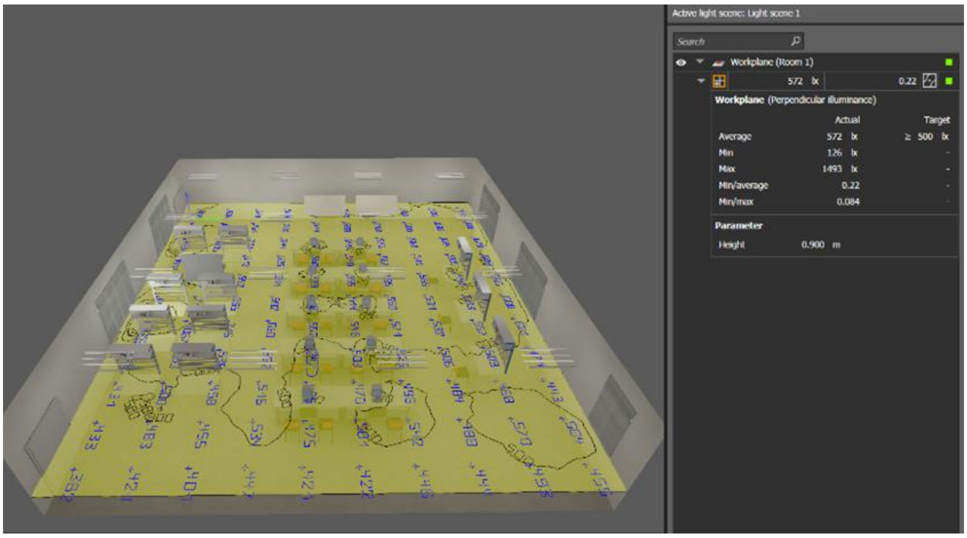

Figure 1. Simulation result for the ME 18 laboratory before improvement

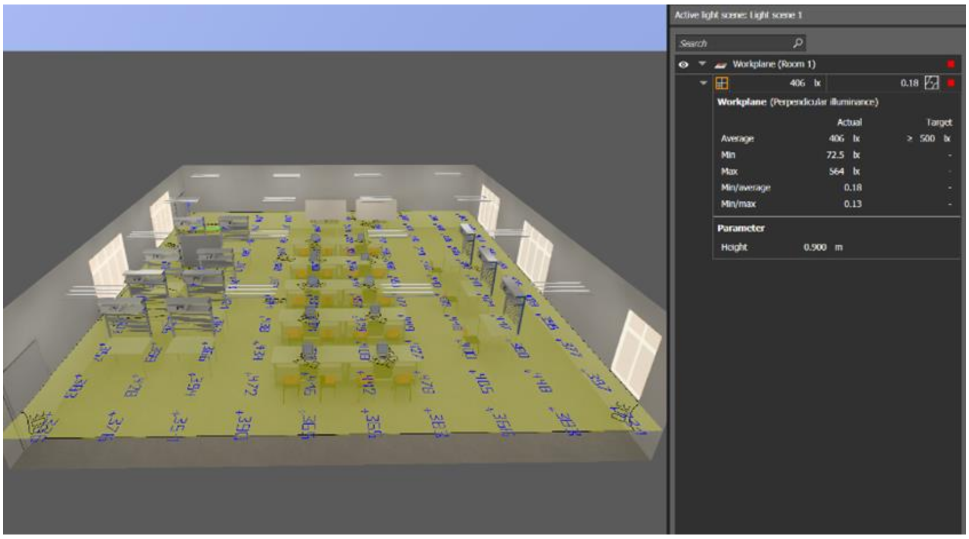

Figure 2. Simulation result for the ME 18 laboratory after improvement

4. CONCLUSION

Using the appropriate lighting system in lecture rooms and laboratories is essential to improve the teaching and learning environment. According to the MS 1525 standard, the illuminance levels required for classrooms and laboratories are 300 and 500 lx, respectively. Hence, it is crucial to determine the illuminance levels of lecture rooms and laboratories in an academic building to ensure that the rooms fulfill the illuminance level requirements stipulated in the MS 1525 standard. In this study, simulations were performed using DIALux evo 10.0 lighting design software to determine the illuminance levels of four lecture rooms and six laboratories in the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia. The results showed that the illuminance levels of the lecture rooms were significantly higher than the required illuminance level of 300 lx, indicating that the rooms were overlit and may cause discomfort to both academic staff and students. The results also showed that three laboratories were underlit whereas the other three laboratories were adequately lit. Suggestions were made to improve the illuminance levels inside the lecture rooms and laboratories. Based on the results, it is essential to study the relevant design guides and assess the layout of the lecture rooms and laboratories before setting up a lighting system since the room dimensions, lamp type, number of luminaires, and lighting arrangement all affect the illuminance level.

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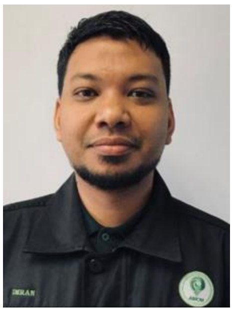

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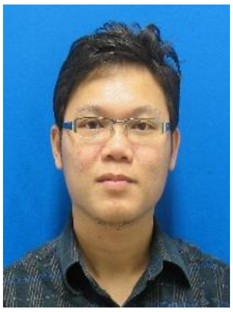

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