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Lighting system design according to different standards in office building: A technical and economic evaluations

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Lighting system design according to different standards in office building: A technical and economic evaluations

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Abstract. Lighting system is an important sub-system in office buildings. A good design can contribute energy saving and visual comfort to occupants. This paper presents a comparison of lighting system design according to different standards: European Standard EN12464-1 and Malaysian Standard MS1525 in terms of average illuminance level and illuminance uniformity. In the design, the illuminance measurement is according to the Illuminating Engineering Society of North America (IESNA) and the European Standard EN12464-1. Three types of luminaires are considered which are: T8, T5 and light emitting diode (LED) lamps. The technical and economic evaluations are taken into account in this paper. The technical evaluations are considered the number of luminaires, average illuminance level and illuminance uniformity. The energy consumption (EC) and lighting energy numeric indicator (LENI) are considered according to the European Standard EN15193. Meanwhile, the economic evaluation involves billings and luminaires costs and billing savings. The case study is an office room and it is modelled and simulated using DIALux software. The results show that the design according to the European Standard EN12464-1 with uniformity based method that used T5 lamps had contributed to the highest number of luminaires and costs. Whereas, the design according to the Malaysian Standard MS1525 with illuminance level based method that used LED lamps had contributed to the lowest number of luminaires and costs. Thus it can provide the higher billing savings. It can be concluded the LED has great potential to replace T8 and T5 lamps.

1. Introduction

Lighting system is one of important sub-systems in buildings beside heating, ventilation and air condition (HVAC) and plug loads. Lighting system accounts 20 - 45% of their energy consumption [1]. In U.S, lighting consumed 10% of total electricity energy in commercial buildings [2]. Numerous lighting system design guides were published to help engineers to design in order to fulfil the standards. The standards and green building rating systems such as Leadership in Energy and Environment Design (LEED) are incorporated the guides. Some examples of the guides are The Installer's Guide to Lighting Design [3], Lighting Design Guide [4] and The Lighting Handbook [5].

Dubois et al. [6] reviewed the electrical lighting retrofit to minimize energy used in buildings. They outlined lighting retrofit strategies which are: lamp, ballast and luminaires replacement, retrofits with light emitting diode (LED) lamps, retrofits with T8 and T5 lamps and reduction of maintained illuminance levels. Ganandran et al. [7] studied the potential energy saving of the lighting system by retrofit LED bulb in several buildings of Universiti Tenaga Nasional, Malaysia. In the study, they calculated the electricity savings, payback period and potential benefit to environment. Vahl et al. [8] carried out techno-economic analysis of lighting retrofit CFLs and LED lamps. In the study, they analysed the equivalent annual cost (EAC) and net present value (NPV). Mahlia et al. [9] studied the economic perspective in term of retrofit T8 and T5 lamps was conducted in Universiti Malaya, Malaysia. The economic perspective includes payback period and life cycle cost. Gan et al. [10] examined the feasible potential cost-benefit analysis for three types of lamps: T8 lamps, T5 lamps and LED tube on several blocks of Universiti Teknikal Malaysia Melaka, Malaysia. Halim et al. [11] evaluated lighting retrofit LED in term of economic evaluation. In the study, they calculated simple payback period and NPV.

Aforementioned studies are only considered in term of economic evaluations. In this paper, the lighting system design will be based on different lighting system standards which are the European Standard EN12464-1 and the Malaysian Standard MS1525. The results will be presented in terms of technical and economic evaluations. In technical evaluation, the illuminance levels and illuminance uniformity will be compared based on different standards. Meanwhile, for economic evaluation the billings and luminaires costs will be calculated and compared for both standards. Moreover, the type of luminaires which are T8, T5 and LED lamps will be taken into analysis in order to compare their performances.

1.1. Standards related to lighting system design

Standard is documents of guidelines, specifications and requirement about technical system. In terms of energy and environmental management standards, the standards help to minimize energy consumption, reduce environmental impact, reduces waste and more sustainable. Various standards are established by standard organizations or institutions such as American National Standards Institute (ANSI), Illuminating Engineering Society of North America (IESNA), European Standard, Malaysian Standard and so on according to their subject matter experts. For lighting, energy efficiency and renewable energy subject, some standards were established such as the IES Lighting Handbook by IESNA, the European Standard EN12464-1 by European Committee for Standardization and the Malaysian Standard MS1525 by SIRIM Berhad.

1.1.1. European Standard EN12464-1

The European Standard EN12464-1: Light and lighting – Lighting of work places – Part 1: Indoor work places [12] was published on November 2011and it was produced by European Committee for Standardization. The standard members are the nation of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom. The main objective of the standard is to establish technical guidelines for design, maintenance and verification that focus to indoor lighting system in work places.

1.1.2. Malaysian Standard MS1525

The Malaysian Standard MS1525: Energy efficiency and use of renewable energy for non-residential buildings – Code of practice was revised in 2014 [13] and it is one of the Malaysian Standard which was developed by SIRIM. The standard helps architects and engineers to design the building, lighting and electrical systems, air conditioning and mechanical ventilation systems and energy management systems. The standard provides technical guidelines for both interior and exterior of lighting systems. The summary of maintained illuminance level ($\overline{E}_m$) and illuminance uniformity (U_o) for different standards in general office is presented in Table 1.

Table 1. Summary of maintained illuminance level ($\overline{E}_m$) and illuminance uniformity (U_o) for different standards in general office

Ref.[a]	Standard	$\overline{E}_m$ (lx)	U_o
[12]	EN12464-1	500	0.6
[13]	MS1525	300-400	Not specified

[a] Reference

2. Interior lighting system design

In building design process, after an architect has completed the building design, the mechanical and electrical (M&E) engineers take place for design processes. The design includes HVAC and electrical circuit and lighting systems. The lighting system design involves several considerations such as luminaires, design methods (illuminance and uniformity based), illuminance level measurement, daylighting and sensor placement.

2.1. Luminaire specifications

Luminaire consists of lamp that emits amount of visible light. Scientifically, it is also known as luminous flux (Φ) which is measured in lumen (lm). In luminaire data sheet, the specifications provides commonly such as lumen output/luminous flux, input power/wattage, luminous efficacy, colour temperature, Colour Rendering Index (CRI) and polar intensity diagram.

2.2. Illuminance level based

Illuminance level based method also known as lumen method is the most widely used method to calculate illumination for interior lighting design. Moreover, most of the lighting design softwares utilized this method for calculating the number of luminaire such as DIALux. This method is recommended by [14] in order to determine the illuminance level by considering the luminous flux, room area and

others parameters related to lamp. Illuminance (E) describes the amount of luminous flux on the surface of the room. The SI unit of illuminance is lux (lx). The total number of luminaires (Nl) in the room can be expressed in equation (1) as follows:

$$Nl = \frac{E_{avg} \cdot A}{n_l \cdot \Phi_n \cdot UF \cdot MF \cdot BF} \tag{1}$$

where, E_{avg} is the average illuminance according to the standard measured in lux (lx), A is the area of the room in meter square (m^2), n_l is the number of lamp for each luminaire, Φ_n is the nominal lumen output for each lamp in lumen (lm), UF is utilization factor provided by luminaire manufacturer based on room index, MF is the maintenance factor and BF is the ballast factor. The typical value of UF and BF are 0.9 and 1, respectively. The most common value of MF is 0.8 that used in lighting system design and is also stated in OSRAM [15].

2.3. Illuminance uniformity based

Illuminance uniformity which also called as uniformity represents the quality of the illuminance distribution on surface or area either interior or exterior. The most widely used of uniformity is global uniformity (U_o) and express in equation (2).

$$U_o = \frac{E_{\min}}{E_{avg}} \tag{2}$$

where, E_{min} is the minimum value calculated of illuminance and E_{avg} is the average illuminance value calculated.

2.4. Illuminance level measurement

To determine the value of illuminance level, two ways are used that are real field measurement and lighting software package. The real measurement is carried out using lux meter based on measurement point of the area. Meanwhile, the method by using lighting software package takes lesser time to calculate the value of illuminance for each measurement point compared to real measurement method. Beside time consuming, the other advantage of using software package is faster generated results such as average, minimum and maximum illuminance values, global uniformity (U_o) and graphical contour illuminance level.

The measurement points of illuminance is forms of grid either square or rectangular grids. According to European Standard EN12464-1 [12], the maximum grid size (p) can be determined by using equation (3) as follows:

$$p = 0.2 \times 5^{\log_{10}(d)} \tag{3}$$

where, d is longer dimension of the area (m)

On the other hand, according to the IESNA [14], the illuminance measurement grid size is square (0.66 x 0.66 m^2).

3. Methodology

This section describes and discusses the methods that are used in this study. The sub-section includes building and lighting system design, illuminance level measurement, analyse the energy and the economic performances.

3.1. Building and lighting system design

The case study is an actual office room, department of Mechanical Technology, Institute of Industrial Training, Selandar, Melaka, Malaysia. The office dimensions are (20 x 8 x 2.7 m^3) and it is illuminated by 24 luminaires (8 by 3 grids). Each luminaire consists of 2x36W T8 fluorescent lamps.

The building and lighting system designs were carried out using DIALux software. The DIALux is the most widely used lighting software which was developed by DIAL GmbH, Denmark with over 600,000 users worldwide [16]. The software is free and it can perform both interior and exterior lighting designs.

In this study, the lighting system design is according to two standards which are European Standard EN12464-1 and Malaysian Standard MS1525. Two parameters were considered that are average illuminance level (E_{avg}) and illuminance uniformity (U_o). Different types of luminaires will be considered in this study which are: T8 fluorescent, T5 fluorescent and LED lamps and the luminaire grid size will be determined based on lighting design parameters and standards. The luminaires specifications are provided in Table 2.

3.2. Illuminance level measurement

The illuminance level measurement was performed on horizontal plane with 0.75 m high from the floor using DIALux software. The measurement is according to two standards that are: the IESNA and the European Standard EN12464-1. According to the IESNA, the illuminance level measurement grid is (0.66 x 0.66 m^2). Whereas, according to European Standard EN12464-1, the illuminance level measurement grid will be calculated using equation (3).

3.3. Analyse the energy performance

In this study, the energy performance that was analysed are annual energy consumption (EC) and lighting energy numeric indicator (LENI) which are according to the EN 15193 [17]. The EC and LENI are measured in kWh/year and kWh/year/m^2, respectively. The LENI is the sum of energy consumed include daytime, night-time and parasitic energy used divided by the area. The calculation of EC and LENI were performed using DIALux software.

Table 2. Luminaires specifications

Type of luminaire	Total luminous flux (lm)	Total power (W)
T8	6700	72
T5	6600	70
LED	7450	50

3.4. Analyse the economic perspective

In economic analysis evaluation, three parameters were considered in this study are: energy billings and luminaires costs and billing savings. In this case, the latest electric tariff from Tenaga Nasional Berhad which is the national electricity provider is RM 0.365/kWh [18]. Based on market survey, the prices of luminaires are as follows: T5 fluorescent lamp (RM 35) and LED (RM 52). Moreover, the simple payback period (SPP) was evaluated in this paper. SPP can be described as estimated project cost divided by estimated billing savings.

4. Results and discussion

This section presents the simulation results from DIALux. The simulation results include 3D model of office with luminaires, technical and economic analyses.

4.1. Building and lighting design using DIALux

The 3D model of office with luminaires on the ceiling was performed in DIALux is illustrated in Figure 1. The model includes 4 workstations, 1 set coffee table with 2 chairs, copier, a table with printer, 5 file cabinets and 24 luminaires.
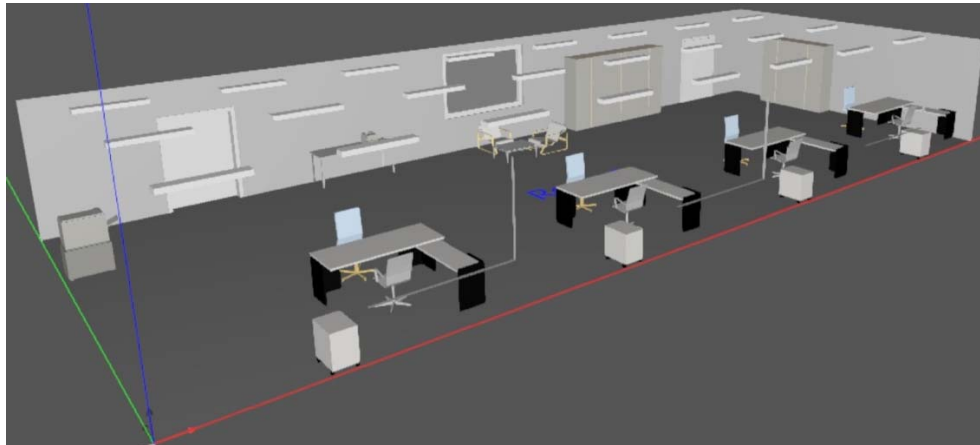
Figure 1. 3D model of office room with luminaires on the ceiling in DIALux

4.2. Technical analysis results

The results of illuminance level, uniformity and luminaire grid for different standards, design methods and type of luminaires are shown in Table 3. Based on Table 3, the MS1525 with T8 lamp is existing luminaires in the office room and the rest are feasible analysis in this paper. The existing design clearly showed that it is over design in term of number of luminaires due to the E_{avg} is significantly higher than 300-400 lx according to Malaysian Standard for general office. Because of this, the lighting system consumed higher electricity energy and waste it consequently. According to Malaysian Standard, they consider the E_{avg} value only, thus, the value of E_{avg} always lesser than E_{avg} value that design according to European Standard for all type of luminaires. The illuminance uniformity based method is significantly contributed higher number of luminaires for both standards and the whole type of luminaires compared to illuminance level based method. Consequently, the illuminance level and uniformity explicitly showed that higher values. The higher luminaires grid which contributed from design according to the EN12464-1 with uniformity based method that used T5 lamps is (8 by 5) grids equal to 40 luminaires. Meanwhile, the lowest luminaires grid is design according to the MS1525 with illuminance level based method that used LED of (3 by 3) grids equal to 9 luminaires.

For illuminance measurement grid size according to the IESNA, it is clearly showed that the E_{avg} and U_o values always less than which used EN12464-1. The smaller size of illuminance measurement grid the more number of measuring point are obtained thus, the points almost covered the overall horizontal workspace plane.

Simulation results of energy consumption and LENI for different standards, design methods and type of luminaires are presented in Table 4. Based on Table 4, the highest energy consumption and LENI which contributed from design according to the EN12464-1 with uniformity based method used T5 lamps are 7950 kWh/year and 50 kWh/year/m^2, respectively. Meanwhile, the lowest energy consumption and

LENI are design according to the MS1525 with illuminance level based method used LED of 1150kWh/year and 7 kWh/year/m^2, respectively.

Table 3. Simulation results from DIALux of illuminance level, uniformity and luminaire grid for different standards, design methods and type of luminaires (ToL)

Standard/design method/ToL	IESNA (M)		EN 12464-1 (M)		Luminaires grid
	E_{avg}	U_o	E_{avg}	U_o	
MS1525- T8	502	0.58	514	0.79	8 x 3
MS1525(E) - T5	342	0.50	349	0.62	5 x 3
EN 12464-1 (E) - T5	536	0.57	546	0.77	6 x 4
EN 12464-1 (U) - T5	879	0.61	897	0.78	8 x 5
MS1525(E) - LED	320	0.33	328	0.46	3 x 3
EN 12464-1 (E) - LED	528	0.54	540	0.67	4 x 3
EN 12464-1 (U) - LED	966	0.61	985	0.78	7 x 4

E is illuminance level based design
U is uniformity based design
M is illuminance measurement grid according to the standard

4.3. Economic analysis results

Luminaires and billings costs and billing savings for different standards, design method and type of luminaires are shown in Figure 2. Based on Figure 2, the highest luminaires and billings cost which contributed from design according to EN12464-1 with uniformity based method used T5 lamps are RM 1400 and RM 2902 per year, respectively. Meanwhile, the lowest luminaires and billings costs are design according to MS1525 with illuminance level based method used LED of RM 468 and RM 2412 per year, respectively. Moreover, it is contributed to the highest billing savings up to RM 1194 per year. It showed that the LED is leading the lowest cost in term of billings and luminaires costs and the highest billing savings.
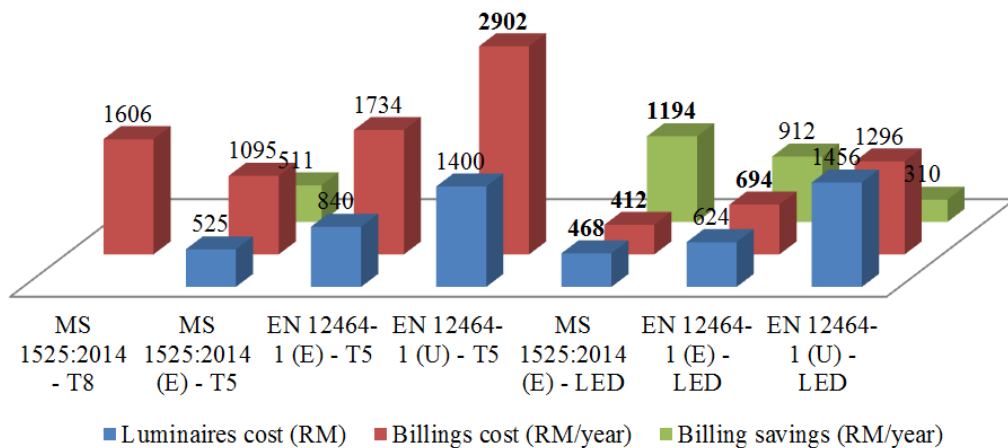
Table 5 shows simple payback period (SPP) for different standards, design methods and type of luminaires (ToL). As can be seen from Table 5, the lowest SPP is design according to MS1525 with illuminance level based method used LED of 0.39 year about 7 months. Meanwhile, the highest SPP is design according to EN12464-1 with uniformity based method used T5 lamps of 4.7 years about 57 months. Lighting design based on illuminance level using LED lamps showed that SPP less than 1 year for both standards.

The lighting system design according to EN12464-1 with uniformity based on method that used T5 lamps explicitly showed that it leads the number of luminaires grid for both technical and economic evaluation. The luminaires grid is propotional to E_{avg}, U_o, EC and LENI. LED lamps are highly recommended to retrofit T8 lamp due to superior performance in technical evaluation and very economic. This finding supports previous studies [7-10] and has conluded that LED has great potential to replace flourescent lamps and reduce energy consumption consequently.

Table 4. Simulation results of energy consumption and LENI for different standards, design methods and type of luminaires (ToL)

Standard/design method/ToL	EC (kWh/year)	LENI (kWh/year/m^2)
MS1525- T8	4400	27
MS1525(E) - T5	3000	19
EN12464-1 (E) - T5	4750	30
EN12464-1 (U) - T5	7950	50
MS1525(E) - LED	1150	7
EN12464-1 (E) - LED	1900	12
EN12464-1 (U) - LED	3550	22

Figure 2. Luminaires and billings costs and billing savings for different standards, design methods and type of luminaires

Table 5. Simple payback period (SPP) for different standards, design methods and type of luminaires (ToL)

Standard/design method/ToL	SPP (year)
MS1525:2014 (E) - T5	1.03
EN16434-1 (E) - T5	-
EN16434-1 (U) - T5	-
MS1525:2014 (E) - LED	0.39
EN16434-1 (E) - LED	0.68
EN16434-1 (U) - LED	4.70

5. Conclusion

The aim of this paper is to compare the lighting system design according to different standards in terms of technical and economic evaluations. The findings showed that the lighting system design according to the EN12464-1 with uniformity based method that used T5 lamps contributed higher luminaires grid and higher values consequently of E_{avg} and U_o which contributed higher billings and luminaires

costs. The second finding had stated that the illuminance measurement grid according to the IESNA contributed lower values of E_{avg} and U_o due to smaller size of grid compared to the EN12464-1. It was also showed that LED was the vast potential to replace fluorescent lamps due to superior performance in term of technical and economic.

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