Journal of Engineering Science and Technology
Vol. 14, No. 4 (2019) 2140 - 2151

REDESIGNING STREET-LIGHTING SYSTEM USING LED AND HPS LUMINAIRES FOR BETTER ENERGY-SAVING APPLICATION

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Abstract

Street-lighting system is designed to give comfort to users by considering the energy efficiency aspect and suitability with the lighting standard. This paper elaborates the evaluation results of conventional street-lighting in one of the roads in Bandung, Indonesia. The experiment was done by analyzing two types of lamps used for the street lighting system: i.e., high-power Light-Emitting Diode (LED) and High-Pressure Sodium (HPS). To analyse the intensity and the energy used, a numerical simulation was conducted using DIALux software. The experimental results showed that several aspects are required to get energy-saving light, such as carbon emission reduction, quality of the light, life cycle cost, energy consumption, infrastructure, and support to a smart city. The results can be used as feedback for redesigning a better energy-saving and economical energy usage. In addition, technical aspects and investment are also important considerations to redesign the street-lighting system.

Keywords: Energy saving, Street Illuminance, Light uniformity, Power quality, System.

1. Introduction

The street lighting system is one of the most important facilities in cities. This system can increase the safety of road traffic participants and give pedestrians' sense of security on the other. Public street lighting can also reduce crimes at night [1-3]. Specifically, in the busy areas, many people are walking around all night long, or moving from one place to the workplace, home, shopping tour, malls, restaurants, and cinemas (or the other way around).

Herbert and Davidson [4] proposed that street lighting provides much influence on people's lives. Excellent street lighting increases the number of residents to use the streets during the night. According to Szakonyi and Urpelainen [5], such an excellent scenario demands the street lighting system to be constant, continuous, and appropriate for illumination of streets. However, this constant lighting system has a strong correlation to the use of energy, as energy consumption is a great issue for the city itself due to its relation to the cost that must be paid. Thus, possible ways for energy savings in the public street lighting systems are discussed recently [1, 2, 5-19].

Street lighting contributes about 2.30% of global electricity consumption [17]. Accomplishments to reduce the waste of energy from street lighting have been realized by many countries; for instance, in the last 12 years of electricity consumption in Spain has been successfully lowered [13]. Indeed, using smart and excellent strategies for gaining efficient street lighting, reduction of the carbon emissions and realization of significant electricity cost can be obtained [20, 21].

The simplest way for the reduction of electricity consumption is by minimized number of street lighting. However, the reduction of street lighting at night without considerations and calculations will have an impact on road accidents and crimes [20]. Therefore, the consideration of energy-efficiency planning needs to be executed carefully. Road lighting systems are usually designed and operated to satisfy the lighting standards, minimize power consumption, and increase user's comfort and aesthetics [7, 17].

Conventional street lighting utilizing mercury lamps usually consumes high electrical power [22]. New light sources have emerged such as spotlight halogen, Light-Emitting Diode (LED), and compact fluorescent light [11, 19]. Based on studies by Nandiyanto et al. [23], Sastry et al. [24] and Pattison et al. [25], among them, LED is believed as the best choice because, in addition to relatively low required wattage, its energy is very efficient, and it has a long operational life of up to 50,000 h or longer [23-25]. The LED technology has a great efficiency, which reaches more than 110 l m/W, while the classic lamp is less than 75 l m/W [12]. The LED technology is always proposed to be an approach to minimize the energy consumption and operating costs of street lighting [16].

Based on our previous studies in the development of a system for analyzing the lighting for many purposes [23, 26-31], the purpose of this report is to analyze the optimal illuminance level based on standardized lighting. Corrections and recommendations related to the energy efficiency and electricity tariff with lamp replacements using high-power LED and HPS are then performed. In this study, the LED and HPS lamps were from the same producer with equal frequency. The feasibility of energy efficiency of street lighting using high-powered luminaries of about 100 W, installed in the main city road having a total length of 384 m is further studied. This illumination system is selected because the data can be obtained easily, with a handheld lux meter. The redesign of street lighting refers to the standard of street lighting issued by the Indonesian National Standard, which in the Indonesian language, stands for *Standar Nasional Indonesia* (SNI).

The process for redesigning street-lighting uses a DIALux software (the most commonly used software for in the street-lighting analysis). DIALux is usually used for indoor, outdoor, and street lighting. Designers can use types of lamp that are available in the market. This can be done by downloading the catalogues of lamps from various manufacturers. The download can be accessed through official websites of the manufacturers or through catalogue menu on DIALux. The software also supports designers to have results of their planning in either 2- or 3-D model and can be saved in various formats (e.g., AutoCAD, pdf, dxf, and jpg).

2. Material and Method

The study started with a survey on the existing condition of roads whose lighting system would be evaluated. The study was conducted in one of the most populous and the busiest roads in Bandung, West Java, Indonesia (6.91°S, 107.60°E; shown in Fig. 1(a). The information on the site of the research is shown through Google Map I (in both map and satellite map) in Figs. 1(b) and (c). The photograph image of the evaluated location is shown in Fig. 1(d). The complete data of the road is in the following:

- Name of the street/type of street: Wastukencana/Secondary Collector Street.
- Rules of illumination method lighting (SNI): 3-7 lx.
- Length/width: 383.79 m/11.77 m.
- Width of the right side/left side: 5.68 m/5.17 m.
- Traffic system: One way.
- Number of lanes: 3 lanes.

The location is classified as one of the busiest roads in Bandung because there are a city government centre, a school, factory outlets, office of the city community service, a mosque, and a church. Thus, there is no way for not giving good quality of lighting, especially in the night time. But, in addition to the good quality of lighting, the efficiency of energy use must be also considered.

Illumination measurement was carried out to identify the lighting quality of the existing condition. The measurement was at an elevation angle of 45o beneath the poles of the street lighting. The measurement of illumination and uniformity had been done three times and the average was obtained.

Lighting measurement (illumination) was conducted on December 11, 2017, at 21.30-24.00 WIB (West Indonesian time). The device for analysing the street lighting was a handheld light meter LX-113S. The specification of the device includes LCD screen (44 mm × 29 mm), photodiode filter sensor, colour correction, and spectrum with International Commission Illumination standard. Automatic measurement of the device can be carried out in two types: lux (l×) and feet-candle (ft-cd). The detailed information of the measurement is listed in Tables 1 and 2.

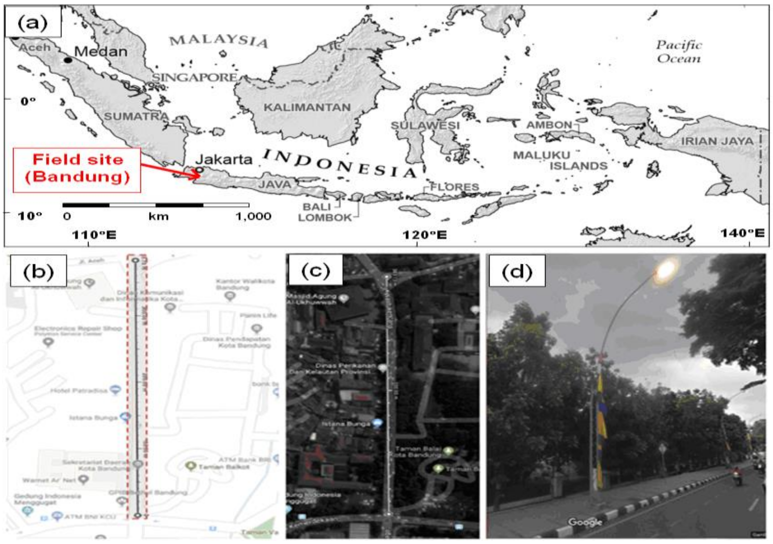

Fig. 1. The field of measurement site: (a) Location of field site [32], (b) and (c) Photograph taken from Google map (December 2018), (d) Map location based on satellite map (December 11, 2017),(e) Photograph image of one of evaluated lamp.

Table 1. Specification of light meter LX-113S (IN LX).

Range (lx)	Range performed (lx)	Resolution (lx)	Accuracy
2,000	0 - 1,999	1	± (5% + 4 l×)
20,000	2,000 - 19,990	10	± (5% + 40 l×)
50,000	20,000 - 50,000	100	± (5% + 400 l×)

Table 2. Specification of light meter LX-113S (IN FT-CD).

Range (ft-cd)	Range performed (ft-cd)	Resolution (lx)	Accuracy
200	0-199.9	0.1	± (5% + 0.4 ft-cd)
2,000	200-1,999	1	± (5% + 4 ft-cd)
5,000	2,000-5,000	10	± (5% + 40 ft-cd)

To measure the distance among poles, the width of the road, the width of the sidewalks, the length of the road, and the height of poles, a digital laser device (BOSCH DLE 70 3 601 K16 670) was used.

The use of a digital laser meter was selected because of its simple measurement. The device also gave more accurate results in comparison with a manual meter. The device was equipped with a laser component called diode, which is able to catch wavelength up to 635 nm, with less than 1 mW energy.

The laser was categorised into a class #2 measurement tool and could measure distance ranging from 0.05 to 70 m. The road is currently using HPS 250 W lamp. The redesign process used two schemes of the lamps.

The first scheme was LED, and the other was HPS. The details of both types of lamps are shown in Table 3.

The process of redesigning street-lighting this study uses DIALux software.

Table 3. Schemes of redesigning plans of street-light system.

Input variables	Scheme 1	Scheme 2
Distance of pole to road	1.80 m	1.80 m
Minimum illumination criterion	5 l×	5 l×
Uniformity	0.10	0.10
Type of lamp	Light emitting diode (LED)	High pressure sodium (HPS)
Manufacturer	Philips	Philips
Type	BGP353 T45 1XGRN 146-2S/657 A	SGP352 1XSON-TPP100W EB FX1 P9H2V
Efficiency	96 l m/W	76 l m/W
Lumination flux	14,560 l m	10,700 l m
Power	128 W	112 W
Type of pole	Single row	Single row
Distance among poles	30-55 m	30-55 m
Height of pole	10-13.50 m	10-13.50 m
Overhang	1-3 m	1-3 m
Angle of arm of pole	0^{o}	0^{o}

When using DIALux, several parameters must be inputted, such as the light loss factor, the width of the sidewalks, the width of the bicycle route, the width of the road, the width of the road median, the number of lanes, and the condition of the road surface. The next parameters involve determining the average speed on the road, the users of the road, the safety level of the road, the traffic, and the pedestrians, and the environment of the street-lighting position. Then, DIALux combines all the aforementioned information to be formulated into a certain standard of lighting based on the rules by the International Commission on Illumination.

In short for the simulation analysis, the factor of light loss was set at 0.80. This was due to the fact that the road was relatively clean and the dust accumulation was assumed to be relatively low. The width of the road was 11.77 m. Regarding the sidewalk, the width of the right sidewalk was 5.17 m, whereas, that of the left sidewalk was 5.68 m. The road surface was black and rough, providing the parameter of the surface was 0.07. When the road was wet, the parameter was set at 0.20.

The next considered parameter was the height of the pole. The height was set at an interval from 10 to 13.50 m with the increase of optimization calculation at every 0.50 m. Light overhang ranged from 1 to 3 m, resulting in the increases in the calculation at 0.50 m. In addition to those conditions, some parameters were fixed. Those were the distance of the poles to the roadway (1.80 m) and the angle of the arm of the pole (0^{o}).

If all parameters were completed, the next step was to do a calculation to combine one possibility to another. The results of the calculation would create some suggestions on suitable positioning of the lighting as well as certain illumination levels. In this study, the determined illumination level was at 5 l× (minimum) and the uniformity level was 0.10. If there was unsuitable positioning, the software would inform “inadequate” or information that the street lighting did not meet the requirements. There would also be a red light telling that it was inappropriate.

Data on the initial information of the light class will be displayed by DIALux; however, if the designers have their own criteria (based on Indonesian standard with a serial number of SNI:7391:2008), parameters in the DIALux can be adjusted. If the data input is correct, the data need to be validated. In selecting types of lamps, we used lamps that are commercially available and still in production during the research since not every type of lamp is able to be simulated by DIALux. We also considered the policy of some lamp manufacturers. Selection of lamps can be executed by downloading the catalogues from the manufacturers’ official websites.

Prior to running the program, parameters were set in a specific condition. The parameter planning covers interval data or fixed data. The parameters comprise distance among poles, the height of the poles, the distance of the centre point to the lamps, angle of the arm of the poles and types of pole positioning. Designers should select the positioning of the street-lighting based on a combination of the parameters. DIALux is then inform lighting whether meets the standard or not since this system has an ability to measure the energy tariff consumed by the lamps.

3. Results and Discussion

Table 4 shows the results of illumination measurement on the evaluated area. The analysis result in the location revealed that the illumination average of all poles/ points was 44.73 l× and the uniformity average was 0.31604. The existing lighting actually has already passed the SNI standard for lighting in terms of both illumination and uniformity. Specifically, compared to the SNI standard, the values of illumination and uniformity of the street-lighting on the existing condition actually exceeded the lighting standard by more than 8 and 3 times, respectively. This informs the excess of energy consumption, giving ideas to the need for a redesign of the lighting to get saver energy.

To redesign the quality of the lighting, there are two schemes. The first scheme is using an LED lamp and the other is utilizing HPS. The analysis of both schemes based on the DIALux analysis is shown in Tables 5 and 6. Table 5 is the specification of lamps and Table 6 is the simulation result. The result showed that the power of HPS was lower than that of LED although both lamps have identical colour rendering indexes. The different results were due to the luminary value and efficiency. In relation to DIALux, it actually just considers technical aspects of street lighting such as poles, types of lamps, and height. Surrounding environment paid attention included in this area are just road width and road surface colour, and types of the road, whether it is for pedestrians or vehicles, and the space of the sidewalk.

In line with the rules of SNI 7391:2008, the average illumination level of street-lighting type secondary collector ranges from 3 to 7 l×, with the uniformity level at 0.10. In order that the average illumination level is in accordance with the standard of SNI, the minimum criterion was set at 5 l× and the uniformity was at 0.10.

This was to adjust the illumination level to meet the SNI standard criteria even if the lamp performance decreases. Regarding determination of planning parameter, the additional data needed were the pole distance, the height, the light overhang, and the distance of the poles to the roadway. The distance interval input among the poles was between 30 and 55 m with the optimization of increasing calculation every 1 m.

Table 4. Data of illumination and uniformity measurement.

Pole number	Illumination average (l×)
1	16,33
2	35,33
3	28,33
4	32,67
5	40,67
6	33,67
7	28,67
8	29,67
9	28,33
10	19,67
11	31,67
12	47
13	23,67
14	51,67
Illumination total average (lx)	**44,73**
Uniformity	**0,365**

Table 5. Specification of lamps used in schemes 1 and scheme 2.

	Scheme 1	Scheme 2
Type of lamp	LED	HPS
Nominal voltage	220-240 V AC, 50/60 Hz	220-240 V AC, 50/60 Hz
Power	128 W	112 W
Lumination	14560 l m	10700 l m
Efficiency	96 l m/W	76 l m/W
Colour rendering index (CRI)	99	99

Table 6. Simulation result of schemes 1 and 2.

Design of variable	Scheme 1	Scheme 2
Type of lamp	LED	HPS
Average of illuminance	5.38 l×	5.01 l×
Uniformity	0.104	0.099
Pole distance	55 m	52 m
Height of pole	13.5 m	10 m
Overhang	1 m	1.5 m
Boom angle	0º	0º
E_{min}	0.56 l×	0.5 l×
A_{max}	16 l×	22 l×

Figures 2 and 3 are the illumination distributions in Schemes 1 and 2, respectively. Visualization of the 3-D surface showed the real condition of street-lighting of the evaluated site. The lighting distribution was displayed in different colours. The colour index explained the difference in illumination. Those nine colour indexes ranged from 0 to 26 l×. In scheme 1, the illumination average was obtained from 304 spots and in scheme 2 the average was obtained from 288 spots.

Based on the simulation results of both schemes, all recommendations could be implemented in the study area since they met the SNI standard. Both schemes had almost equal uniformity level yet the illumination was better when using LED. It is also shown that the boom angle, which is defined as the light falling spot, is zero.

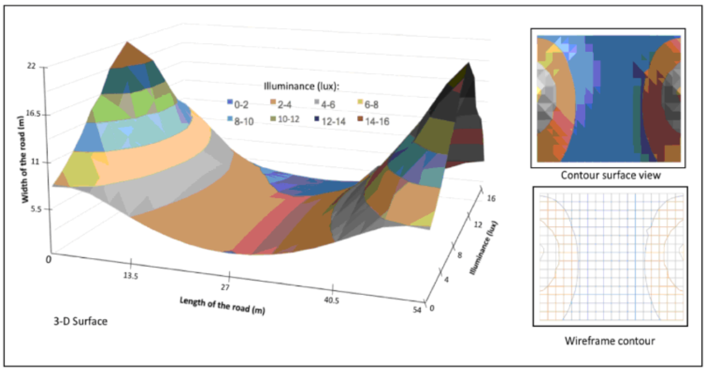

Fig. 2. Illumination distribution of scheme 1.

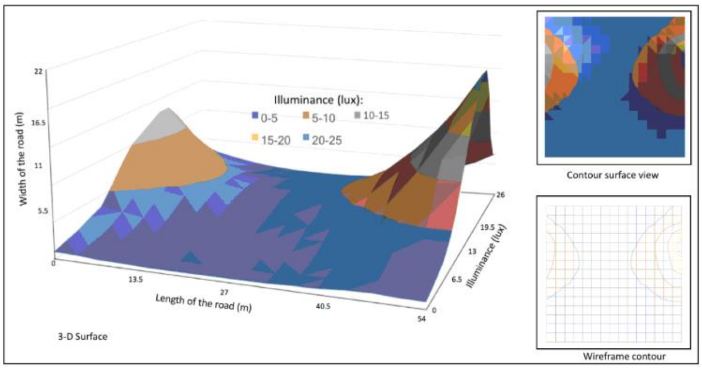

Fig. 3. Illumination distribution of scheme 2.

The simulation results of both schemes technically gave good recommendations. Either scheme 1 or scheme 2 actually created almost identical designs between the use of LED and the use of HPS. Although both schemes had almost equal illumination values and met the standard of street-lighting, the differences of recommendations lied merely on the distance among poles, the height of the poles, and the overhang. These differences would actually affect investment. For instance, in terms of the number of poles needed, LED gave more advantages since it needed fewer poles in comparison with HPS, as indicated by the longer pole distance of 55 m. However, LED needs taller poles compared to HPS; so that, there needs to be further calculation and discussion in relation to the investment budget. However, this paper does not discuss economical calculation and investment of street lighting.

Table 7 displays the comparison of total power consumed and tariff for energy per month for both schemes. For consideration, the calculation of power and tariff of the existing street-lighting was also put on the table. The total power was calculated by multiplying the number of poles with the power of each pole, while energy tariff was calculated by multiplying the energy amount with the basic tariff of the power. According to Indonesian law, the power tariff of 5500 VA is IDR 1076.00/kWh. In Indonesia, the street-lighting system was usually set at 18.00-06.00. Assuming that the street-lighting operates 12 h daily, this study concluded that the power tariff of both schemes saved at least 75.04% of the total power and tariff.

Table 7. Comparison of tariff of energy post-redesign.

Cases	Number of pole	P/ lamp (W)	Intensity (lx)	Uniform	P_{tot} (kW)	Tariff/ month (IDR)
Present	14	250	44.73	0.365	3.5	1,355,760
Case 1 (LED)	7	128	5.38	0.104	0.8	338,365
Case 2 (HPS)	8	112	5.01	0.099	0.89	338,365

Energy efficiency on the street-lighting system was possible using the LED technology since this type had better light quality, low light pollution [6], and could possibly save energy of up to 90% in comparison with the conventional lighting [33]. Therefore, even though LED might need more investment budget [34], it can be considered more effective compared with HPS in terms of life-cycle cost-luminaries [11].

LED technology as a replacement of conventional lamps has been selected since it promotes significant efficiency. Becalli et al. [15] explained that this is understandable since the improvement of lighting quality affects significantly on energy-saving and economic sensitivity. Even though the trend of research on solar photovoltaic (PV) as a solution for street-lighting system power is growing rapidly [27, 31], LED technology is still preferred. This is due to the high cost of investment and time difference of the centre of energy source and the centre of energy consumption [18, 35].

4. Conclusions

Redesigning street-lighting system has been conducted in this study by evaluating the illumination method. One of the roads in Bandung, West Java, Indonesia is selected as the research site. The findings show that the existing condition of the street-lighting remarkably exceeds the lighting standard in Indonesia, illumination is 8 times and uniformity is 3 times; thus, it results in energy waste. According to the simulation results using DIALux software, it is recommended that the existing lamps can be replaced with either LED or HPS technology to get saver energy.

However, LED can be considered more effective than HPS because it offers high potentials of energy-saving, eco-friendly, a better quality of lighting, and long cost life cycle. One of the weaknesses of using LED is that its investment price could be more expensive than a HPS lamp. Regarding the correlation between street lighting and the number of vehicles passing through the road, it is basically related to the right illuminance since when the light intensity is too high, there will be light pollution. When it is right, it will give comfort to drivers, including bicyclists.

Acknowledgement

Authors thank RISTEK DIKTI (Grant: Penelitian Terapan Unggulan Perguruan Tinggi Negeri (PTUPT) and Penelitian Unggulan Strategis Nasional (PUSN)) for supporting this research.

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