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Photometric measurement for LED roadway lighting at Kuala Lumpur – Karak Expressway

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Abstract

This paper presents the measurement of photometric measurements of LED lighting at Kuala Lumpur - Karak Expressway. The aim of this paper is to comply the photometric quantities of LED roadway lighting with International Commission on Illumination (CIE) standard and Lembaga Lebuhraya Malaysia (LLM) requirement. This paper has focused on testing procedure for photometric measurement for LED roadway lighting. The DIALux software is used for lux calculation which in turn will assist in all the photometric calculations. It has been proved that the results were complied with CIE standard and LLM requirement.

Keywords
Light Emitting Diode (LED), High Pressure Sodium (HPS), Luminance, Uniformity

1. Introduction
Malaysian public lighting system employs mostly HPS lamps apart from the preferred High Intensity Discharge (HID) lamps. However, both have their disadvantages. The former produces low colour rendition while the latter contains highly side effect elements like mercury. The high-power light emitting diode (LEDs), once used solely as indicator or luminous flags, is gradually making its presence as roadway lighting. Although LED technology is costly, it is more efficient in terms of brightness, lighting distribution and increased uniformity. Until now, HPS lamps with low colour rendering and high luminous efficacy are the most commonly used light source for roadway lighting in the world.

HPS lamps still outdo LED in efficiency and cost-effective. However, with the recent advancements in LED technology, the efficiency of commercial LED has been developed. Some recent dramatic improvements in luminous efficacy showed a bright prospect for LEDs though the luminous efficacy of LEDs is lesser to HPS lamps [1]. The luminous efficacy is now clearly not that much in favor of the LEDs. However the efficacy of LEDs is increasing continuously with a very rapid speed. The LEDs technology has been significantly improved in the last few years, and they have been considered a promising alternative to the illumination systems [2]. A major advantage of LED roadway lighting is that they last longer than metal halide and HPS lamps since the average life of LED is around 50,000 hours [3].

LED light sources have a higher correlated colour temperature and colour rendering index than HPS lamps. Thus, LED light sources provide superior colour rendition compared with HPS lamps. The colour rendering index (CRI) of LEDs is typically around 60 to 90, whereas the CRI of HPS lamps around 20. The CRI of HPS lamp can be as high as 80 if a colour corrected version of the HPS lamp is used but this lamp is less effective. Contrary to HPS lamps, whose yellowish colour makes it difficult to distinguish color differences in objects, the white light of LED helps discern colour differences in objects [4]. The major advantages of LEDs are their low energy consumption, longer life span, good colour characteristics, improved performance in mesopic vision conditions, instant on, compact size, directical light, reduced light pollution, environment friendly characteristic, dimming capabilities, breakage and vibration resistance, and improved performance in cold temperatures [5].

Most luminance level that is generated by streetlights falls within the mesopic vision range which is generally between 0.001 and 3cd/m^2 [2, 6]. In Toronto, an evaluation on LED and HPS light sources showed LED light appeared brighter and made people and objects much clearer than HPS light. This was due to the higher blue content in the spectrum of LED light. Since the human eye is more sensitive towards the blue end of the spectrum in the mesopic range, LED light with high blue content can be detected more by the human eye [7]. This project dealing with all these parameter and conclude using photometric measurement of roadway lighting.

2. Site Description

The Kuala Lumpur – Karak Expressway, a 60 KM highway was upgraded in 1994 from two lane two way road to a four lane dual carriageway highway. At present, this highway is managed by ANIH Berhad, under the MTD Group of Company. Based on MTD report, the quantity of highway lighting that are use is 971~1000 nos. The road is a dual carriageway with a 1.0 meter middle reserve separation. There are three lanes and one emergency lane on each side of the carriageway. Each lane is 10.5 meter width and the emergency lane is 3.0 meter width.

3. LED Roadway Lighting Measurement

3.1 Lux Testing Setup

Along the longitudinal direction of the road, 10 testing points of equivalent distance were selected between two streets pole when the pole spacing was equal to 35 m. Along the transversal direction of the road, 3 testing points were selected for each individual lane for testing of roadway with good overall uniformity. The first and third point of each lane must be located at transversal length of 1/6 of lane width off each lane edge and the second point must be located in centre of the lane. The purposes of Sample Testing at site were:

- To measure actual illuminance (lux) level at site
- To check overall illuminance uniformity
- To measure actual power factor and total power consumption
- To measure the Total Harmonic Distortion

3.2 Illuminance Testing

Lux meter was placed on each point marked on the pavement to measure the illuminance of each set-up point. The data will be displayed on Lux meter and it will record in the Table of Data Lux Measurements Testing. When the whole data were recorded, then it must be calculated its Overall Uniformity, U_o by using Equation (1) and Average Horizontal Illuminance, E_{av} by using Equation (2). E_{min} and E_{max} also must be identified from the whole data of that testing. The Equation (1) and (2) are as below:

$$U_0 = \frac{E_h \min}{E_h av} \tag{1}$$

$$E_h av = \frac{1}{MN} \sum E_h i \tag{2}$$

Where U_o is the overall uniformity of horizontal illuminance, E_h min is the minimum horizontal illuminance, E_h av is the average horizontal illuminance of roadway, E_h i is the illuminance of i testing point, M and N is grid of tested points on road.

Figure 1 shows the illustration of Lux Measurement Points. The M = 10 and N = 9 are the grid of tested point and the number of M and N are also use in Equation (2) to get the value of Average Horizontal Illuminance, E_{av}. Based on Figure 1, the value of M is 10 and the value of N is 9.

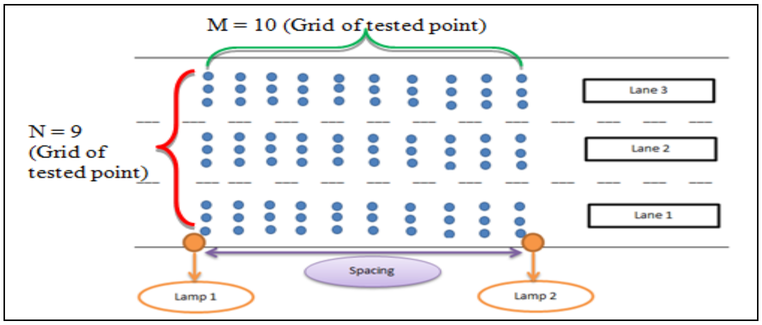

Figure 1: Lux measurement points

3.3. Number of calculation points

Defining calculation points also means defining the field of concern. CIE 30-2 standards the calculation and measurement of luminance and illuminance in road lighting establish that calculation points are to be identified on a road section which include in a span between two luminous centers placed on the same side of the street. Figure 2 demonstrates the steps to draw the number of calculation points on the road. Below are the steps to be taken:

- 5 lines for each driving lane;
- 10 divisions for each span, lower than 50 m starting from the line identified by the first luminous center. The equal distance between them shall be 1/10 of the center pitch;
- For spans longer than 50 m, 50 m away from the lowest number resulting from equal distances not longer than 5 m.

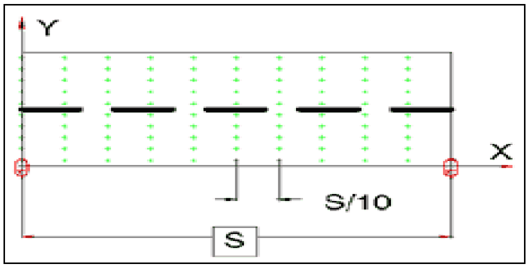

Figure 2: The illustration of number on calculation points

3.4 Observer's position

To calculate luminance, the observer is exactly 60 meters away from the first pole in his direction of view. So the cross-wise position to the road is ¼ of the width of the driving direction, and the distance from the road surface is 1.5 meters. Apart from that, to calculate luminance lengthwise uniformity calculation, the observer is at the center of each lane as shown in Figure 3.

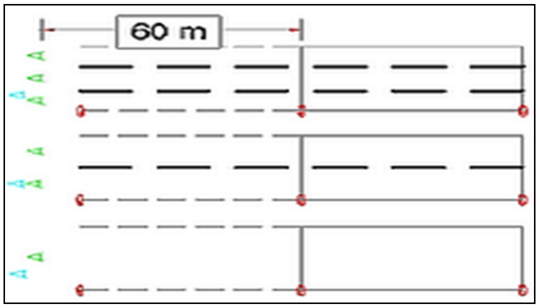

Figure 3: The illustration of observer's position

3.5 Surround ratio

Lighting the area either side of the road is important in allowing drivers to see pedestrians and other road users who may be about to cross the road. The lighting in a zone 5 meters either side of the road should be bright enough so that pedestrians can be seen but not so bright as to change the adaptation state of the driver. The surround ratio (SR) is defined as the ratio of the average illuminance on a 5 meters strip adjacent to the road compared with the average illuminance on the road. This note that, for motorways and other roads where pedestrians are excluded it is not necessary to use the surround rations.

4. Results and Analysis

The lighting calculation process was written according to the newest standards and recommendations published by CIE (International Commission on Illumination) about town roads with vehicle traffic, roads outside the town and urban areas with a single type of luminaire. Calculation is performed on a section defined by two poles on the same side of the road. However, the calculation also includes the illuminance calculation as this is still used as quick discrimination criteria in several cases. Figure 4 shows staffs of ANIH Berhad recorded the data for field testing at Kuala Lumpur – Karak Expresway.

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Figure 4: Lux measurement at site.

As almost all national standards and recommendations are derived from CIE recommendation and argumentations, so it prefers to refer the latter, except for some specific cases in order to have a common reference for all the countries. Table 1 shows the data of Lux Measurement Testing for KM 25 (East Bound). This testing was evaluated on January 2013. The measurement was started at 8.30 pm. By using Equation (1) and Equation (2), the results are E_{av} = 27.8 lux, E_{min} = 22.1 lux, E_{max} = 42.6 lux, E_{min}/E_{max} = 0.48 and U_o = 80%.

Table 1: Data Lux Measurement Testing for KM 25 (East Bound)

Item		1	2	3	4	5	6	7	8	9	10
Lane 1	P1	42.4	42.6	37.3	32.6	26.2	29.7	27.8	31.2	38.2	45.7
	P2	38.0	37.6	33.6	31.5	26.8	29.2	29.0	29.0	34.7	42.o
	P3	32.5	33.0	31.0	29.3	25.6	27.0	28.7	28.1	31.9	38.0
Lane 2	P4	29.5	28.2	29.7	26.1	24.3	25.6	25.9	27.0	29.0	32.1
	P5	25.6	26.4	25.8	25.9	24.0	23.0	24.6	26.2	26.8	31.2
	P6	24.0	24.4	24.6	24.3	23.8	22.1	23.3	25.5	26.2	27.0
Lane 3	P7	23.7	24.0	24.6	24.2	23.8	22.7	23.4	23.7	26.2	29.3
	P8	23.8	24.0	25.2	24.8	24.5	22.9	23.2	25.0	26.1	26.1
	P9	24.2	23.4	23.4	25.3	25.3	23.6	22.8	23.5	25.0	25.5

Table 2 shows the data of Lux Measurement Testing for KM 24.9 (West Bound). This testing was evaluated at the end of March 2013. The measurement was started at 9.30 pm. By using Equation 1 and Equation 2, the results are E_{av} = 30.9 lux, E_{min} = 23.6 lux, E_{max} = 44.6, E_{min}/E_{max} = 0.53 and U_o = 76%.

Table 2: Data lux measurement testing for KM 24.9 (West Bound)

Item		1	2	3	4	5	6	7	8	9	10
Lane 1	P1	43.6	38.9	34.2	30.3	25.6	24.8	30.5	35.1	40.1	44.3
	P2	39.6	36.7	32.7	28.6	24.8	24.7	28.7	32.9	37.0	40.0
	P3	37.2	34.9	31.5	27.3	24.1	24.9	26.4	31.3	34.6	38.1
Lane 2	P4	35.2	33.6	30.3	27.0	24.7	25.8	26.9	30.3	31.8	36.3
	P5	33.7	32.6	29.5	27.0	24.7	26.4	26.9	29.7	32.4	34.2
	P6	32.1	32.0	27.0	26.3	24.6	26.3	26.6	27.7	31.1	31.2
Lane 3	P7	30.3	26.0	24.9	24.8	23.6	25.7	25.7	28.1	29.5	31.0
	P8	29.1	27.8	26.1	24.4	24.2	25.8	25.0	27.3	28.7	30.1
	P9	27.8	26.7	25.8	23.7	23.5	25.1	24.7	26.2	27.5	28.5

Table 3 shows the lux data obtained from field testing and simulation using location of KM 25 East and KM 24.9 West. The recorded illuminance (lux) level basically achieved the required target of average 28 lux set by Lembaga Lebuhraya Malaysia (LLM). Overall, the uniformity results were above requirements as well with nearly 80% overall uniformity achieved. The field data were then compared with the DIALux results to check how well the software result matched the field data for roadway luminaire. Besides, the field data and the software results were compared with the LLM requirement for major roads with high traffic composition conflict.

Table 3: Lux data obtained from field testing and simulation

Item	Description	Requirement by LLM	Lux Report			
			KM 25 East		KM 24.9 West	
			Field data	Simulation	Field data	Simulation
1	Average Lux, E_{av} (Lux)	28	27.8	28	30.9	31
2	Minimum Lux, E_{min} (Lux)	-	22.1	24	23.6	25.2
3	Maximum Lux, E_{max} (Lux)	-	45.6	38	44.6	45
4	Overall Uniformity, U_o(Lux)	>0.4	0.8	0.9	0.76	0.82

Table 4 shows the simulation by DIALux software for the photometric result by CIE (115:2007) requirement. For the lighting class, the M representing for motorized traffic. For this simulation, the speed parameter for motorized was selected to high and traffic volume also very high. These parameters will bring the value of one for Weighting Factor, WF according the calculation by CIE (115:2007). The traffic composition is only for motorized. The parameters for intersection density was selected to moderate, the parked vehicles is not represent because it was a highways. The ambient luminance parameter also selected in moderate and the visual guidance, traffic control were good enough for the motorized. For the parameters above it brings the value of 0 for Weighting Factor, WF. The total of Sum of Weighting Factors, SWF is only 2. So the number for lighting class M is six will be minus two and the total up for four. This is the ways for Lighting Class ME4 was selected Table of Lighting Class M4 by parameters.

The average luminance (L_{av}) for LED roadway lighting is above ≥ 0.75cd/m^2 for both fields. The overall Uniformity (U_o) and the Longitudinal Uniformity (U_I) are above the requirement by CIE as well. From the simulation above, the value of Average Illuminance of Carriageway (E_{av}), the Threshold Increment (T_I) and the Surround Ratio (SR) were follows the CIE requirement as well.

Table 4: Simulation of photometric by CIE requirement

Field	Length (meter)	Width (meter)	Lighting Class	Result				
				L_{av} (cd/m^2)	U_o	U_l	T_I (%)	SR
Requirement by CIE				≥ 0.75	≥ 0.4	≥ 0.6	≤ 15	≥ 0.5
KM 25 East	35	10.5	ME4	1.68	0.7	0.7	8	0.8
KM 24.9 West	35	10.5	ME4	1.68	0.7	0.7	9	0.8

5. Conclusions

This paper examined the field performance of LED roadway luminaires. The mounting height was 12 meters, luminaire spacing was 35 meters and the pavement type was R3 at the test site. The luminaires lit for the two lanes, each lane is 10.5 meter wide. The roadway classification of the test site was assumed as major road with high traffic composition conflict (moderate/high). The sets of illuminance and luminance data were collected. The field data were then compared with the DIALux results to check how well the software result matched the field data for roadway luminaire. Besides, the field data and the software results were compared with the LLM requirement for major roads with high traffic composition conflict. In general, there were different between field measurements and results from DIALux, and some of the LLM criteria were not met depending on the luminaire. The luminance field measurements were conducted using a Hioki 3423 meter that had acceptance angle to provide point by point using the grid. Therefore, individual values for each point are not the same but the measurements for average luminance were accurate and were pressed over the maximum and minimum values. By conducting the field testing and software simulation for photometric measurement at Kuala Lumpur - Karak Expressway, it has been proved that the results were complied with CIE standard and LLM requirement.

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