Jamaludin *et al.*
Journal of Engineering and Applied Science (2023) 70:112
https://doi.org/10.1186/s44147-023-00286-6

Journal of Engineering and Applied Science

RESEARCH

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Investigation of photometric distribution of LED and HSPV for road lighting

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Abstract

Lower energy consumption while preserving the required light brightness is one of the main purposes of changing from an HPSV lighting system to a LED lighting system for road lighting. The current practice of changing whole luminaires requires a huge capital cost. Although LED lamps have a high illumination rate, the lamp structure which is different from existing HPSV lamps may improve the light intensity. This condition causes changes to the original lighting design and may not meet the requirements. Therefore, the aim of this research is to study the photometric distribution of LED and HSPV lamps based on simulation analysis. Both lamps are simulated using Dialux Evo simulation software by varying pole distances according to MS 825:2007 and BS EN 13201-2: 2004 standards. The study involves average luminance, overall uniformity, longitudinal uniformity, and threshold increment parameters. The results show that the average luminance value of the LED replacement lamps is lower than HPSV lamps, with a reduction of 52%. However, there is a minimal change in the light distribution pattern with an overall uniformity difference of 2% and a longitudinal uniformity difference of 18%. The results will be useful for local authorities and manufacturers to study on usage of different LED lighting systems. Energy consumption can be reduced while preserving the required lighting level.

Keywords: Simulation study, Dialux Evo, Average luminance, Overall uniformity, Retrofit, Threshold increment, Pole spacing, High-pressure sodium vapor (HPSV), Light-emitting diode (LED)

Introduction

High-pressure sodium vapor (HPSV) lamps are commonly used for road lighting in Malaysia [1]. The current method of using a light-emitting diode (LED) lamp is a comprehensive conversion. It involves replacing the entire HPSV luminaire with a new complete LED luminaire which comes at a high upfront expense [2]. The LED lamp can replace the HPSV lamp since it is proven to be able to reduce energy consumption while preserving the required lighting level with the advantage of higher color rendering, longer lifespan, and better efficacy [2, 3]. This is a promising method for a low-carbon energy strategy as well as saving energy consumption [4–7].

Even though this is a promising factor, the total replacement of current luminaires with LEDs requires a large capital cost [2, 8, 9]. Luminaire manufacturers have introduced another offer, which is replacing the source of light with LED retrofit bulbs and reusing the original HPSV fittings [10]. The LED replacement lamp consists of light-emitting diodes constructed with a metal heat dissipation structure with a similar lamp base which can improve the energy efficiency of current HPSV luminaires [2]. Usage of existing luminaires can reduce wastage and require a significantly lower investment cost compared to the installation of whole LED luminaires. It is a common practice for indoor installations but rarely carried out for road lighting installations [2].

Although there are many types of LED replacement lamps, research on the light distribution impact for road lighting applications is limited compared to indoor applications [11]. It is due to many safety requirements involving road lighting [1, 3, 9]. Besides general properties of luminaires such as total luminous flux, wattage, and power factor, the luminous intensity distribution (LID) curve which describes the output of luminaires at various angles is one of the main information for calculating or simulating lighting designs [12, 13]. This is to ensure that the maximum efficiency can be achieved regardless of the lighting system. Here, we investigate the changes towards road lighting design illumination when the LED replacement lamp is used instead of the HPSV lamp in the HPSV fixture through computer simulation.

Methodology

The test samples consist of an HPSV lamp (150W) and a LED replacement lamp (68W). No internal modifications were made to the luminaire. Table 1 shows the manufacturer's specifications from the product catalog of test samples (Phillips) in terms of wattage, flux, and correlated color temperature (CCT).

Prior to lighting simulation, the photometric data file which represents the photometric properties of both light sources is obtained from gonio photometric measurement (LISUN LSG1800B Goniophotometer) in the Centre of Excellence for Engineering and Technology JKR. Measurement is conducted based on CIE 121: 1996 standard (The Photometry and Goniophotometry of Luminaires) [14].

Figure 1 shows the flowchart of the simulation study. The simulation process consists of defining the required road parameter and lighting design which involves road width, road surface, luminance coefficient value, and number of lanes. The simulation is continued with lighting setup which involves pole arrangement, light overhang distance, tilting angle of the installed fixture, and maintenance value. Simulation of different pole distances is repeated and compared.

Table 1 Test sample specification

Parameter	HPSV lamp	LED replacement lamp
Wattage	150 W@100 V	68 W@ 240 V
Rated luminous flux	13,500 lm	12,000 lm
Correlated color temperature (CCT)	2000 K	4000 K
Reference	https://www.lighting.philips.com.my/api/assets/v1/file/PhilipsLighting/content/fp928487100096-pss-en_my/928487100096_EU.en_MY.PROF.FP.pdf	https://www.lighting.philips.co.uk/api/assets/v1/file/PhilipsLighting/content/comf7165342-pss-en_gb/LP_CF_7165342_EU.en_GB.PROF.CF.pdf

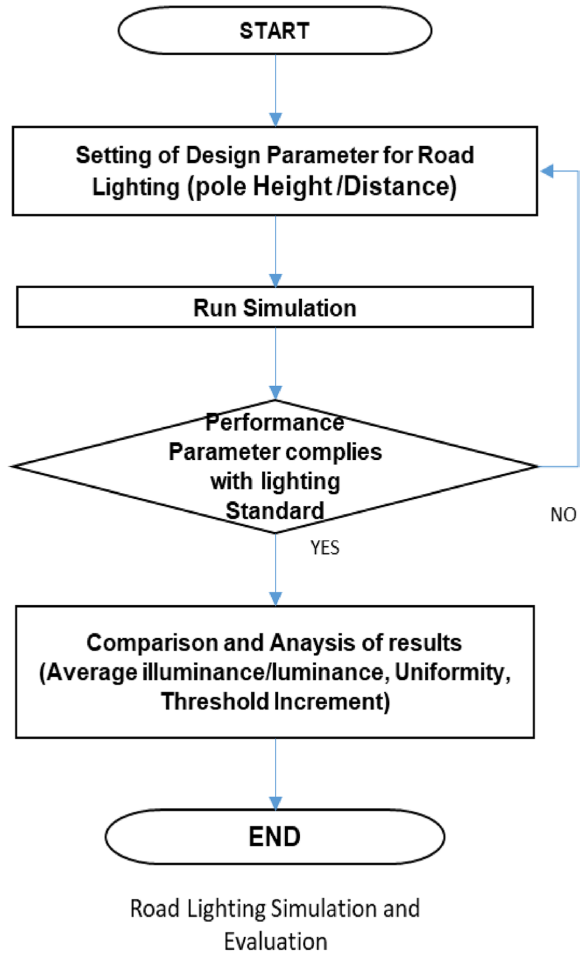


Fig. 1 Road Lighting Simulation flow chart

Table 2 Performance parameters required for ME2 class road lighting [16, 17] (Table 1a BS EN 13201-2:2003 [16, 17])

Performance parameter	Target value
Average luminance	≥ 1.5 cd/m^2
Overall uniformity	≥ 0.4
Longitudinal uniformity	≥ 0.7
Threshold increment	≤ 10%

The simulation is designed for urban roads with a speed limit, not exceeding 60 km/h. Specification of the road design is based on a two-lane single-carriage setup designed as ME2 class road lighting as MS 825 Code Of Practice For The Design Of Road Lighting—Part 1: 2007 Lighting of Road and Public Amenity Area specification [15].

The performance requirement of ME2 class road lighting is shown in Table 2.

The road simulation was set at 3.5 m width per carriageway, with pole height set at 10.0 m, overhang of 1.5 m, luminaire boom inclination of 5.0° with varying distances between 22 and 38 m pole to pole distance, and increment of 2 m. Road specification was set as R3 type rough asphalt road with average luminance coefficient, Q_o ~0.07 for dry road conditions. The maintenance factor was set at 0.83 for ingress protection 66 (IP 66) luminaires in high pollution environments with a cleaning interval of 36 months [15]. The road light design parameter is shown in Table 3.

An analysis is done by comparing the original HPSV lamp and LED replacement lamp using road lighting simulation software (Dialux Evo) based on British Standards [16, 17]. Main road lighting photometric parameters including average luminance (L_{av}), overall uniformity (Uo), longitudinal uniformity (U_l), and threshold increment (Ti) are assessed based on simulation results.

Equations 1 until 3 are used for the analysis of the road lighting simulation results according to BS EN 13201-3: 2003, road lighting calculations [16, 17].

$$\text{Average luminance},\ L_{av} = \frac{\sum L}{n} \tag{1}$$

L = luminance value, n = number of readings

$$\text{Overall uniformity},\ U_o = \frac{Min\, L}{Average\, L} \tag{2}$$

$Min\ L$ = Minimum luminance value on calculation grid
$Average\ L$ = Average luminance value on calculation grid

$$\text{Longitudinal uniformity},\ \text{Ui} = \frac{\text{Min}\, L_c}{Max\, L_c} \tag{3}$$

$MinL_c$ = Minimum luminance on carriageway
$MinL_c$ = Maximum luminance on carriageway

$$\text{Threshold increment},\ \text{TI} = \frac{65}{(average\ road\ luminance)^{0.8}} \times L_v\% \tag{4}$$

Where

$$L_v = 10 \sum_{k=1}^{n} \frac{E_k}{\theta_k^2} \tag{5}$$

$\boldsymbol{L_v}$ is the equivalent veiling luminance (cd/m^2).
E_k is the illuminance in lux, produced by the kth luminaire in the normal plane of the site at the height of the observer's eye at 1.5 m.
θ_k is the angle in degrees of arc between the line of sight and the line from the observer to the center of the luminaire.

Results and discussion

Table 4 shows the measurement result from the goniophotometric measurement used in the lighting simulation. There is a large reduction in light efficiency with a difference in light distribution pattern.

Table 3 Road light design parameters

Parameter	Simulation Setup
Pole to pole distance	22 -38 m (with 2 m interval)
Pole Height (1)	10 m
Overhang (2)	1.5 m
Boom inclination (3)	5.0°
Pole Setup	Double row, opposing
Road width	3.5 m
Number of Lanes	2
Lighting Class	ME2
Surface Type	R3, Asphalt
Luminance Coefficient	$Q_0 = 0.07$
Maintenance Factor	0.83
Roadway condition	Dry

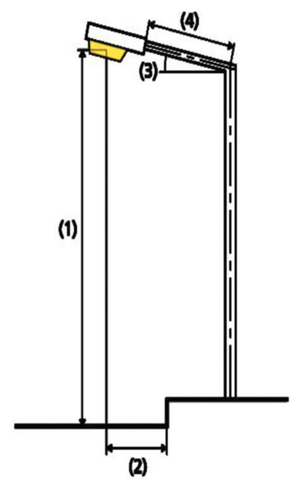
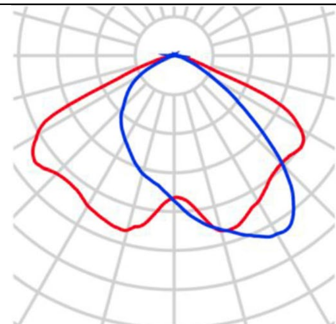
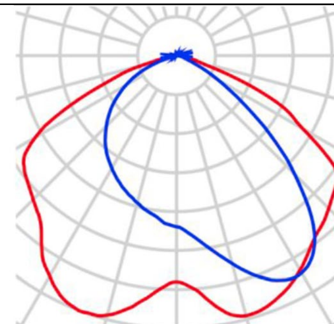


Table 4 Photometric measurement results of HPSV and LED replacement lamp in 150W HPSV fitting

	HPSV LAMP with fitting	LED replacement lamp with fitting
Polar Distribution		
Power	166.7 W	84.2 W
Lamp lumen	13350 lm	11858 lm
Luminaire Lumens	11146 lm	5807 lm
Efficiency	83.49 %	48.97 %
W/km	11003.5 W/km	5555.9 W/km

Figures 2 and 3 show the road lighting simulations from observer 1 employing HPSV lamps and LED replacement lamps, respectively, using an ISO luminance curve with a pole-to-pole distance of 30.0 m. We observe that the simulation of the HPSV lamp has a higher average luminance value than the LED replacement lamp. The average luminance value is 1.71 cd/m^2 for HPSV as compared to the LED replacement lamp illuminance value of 0.83 cd/m^2. The reduction of about 52% can be attributed to the reduction in light output from the luminaire, 11,146 lm to 5807 lm as shown in the measurement results in Table 4. There is a decrease in overall uniformity and longitudinal uniformity which can be seen by the continuous contour in the ISO-illuminance curve in Fig. 2, as compared to Fig. 3 where the ISO-illuminance contour is disrupted within the dotted area.

Meanwhile, Table 5 shows the lighting simulation results at a 30.0-m pole distance with the setting parameter from Table 3. From the results, we can see that the HPSV lamp-fitted light fixture meets the evaluated performance parameters for ME2 lighting requirements with values of 1.71 for average luminance value, 0.75 for overall uniformity, 0.77 for longitudinal uniformity, and 3% for threshold increment while the fixture with LED replacement lamp only complies with overall uniformity with values of 0.71 and 3% for threshold increment. The average luminance value and longitudinal uniformity show only 0.83 cd/m^2 and 0.60, respectively, less than the target, 1.5 cd/m^2 and 0.7.

Figures 4, 5, 6 and 7 show the variation of average luminance (L_{av}), overall uniformity (U_o), longitudinal uniformity (U_l), and threshold increment (TI), with pole distance. The continuous line represents values for the HPSV lamp while the dashed line represents the values for the LED replacement lamp. The dotted line is the value for ME2 lighting class requirements for average luminance, overall uniformity, longitudinal uniformity, and threshold increment respectively as in Table 2. Figure 4 depicts the average illuminance for various pole distances. We observe that the average luminance reduces with the increase of pole distance. The average luminance of HSPV lamps is higher than the LED replacement lamp and the minimum value while the average luminance of the LED replacement lamp is lower than the minimum value. It shows that the HSPV lamp is better than the LED replacement lamp. Figure 5 shows the overall uniformity values of the HPSV lamp and LED replacement lamp for various pole distances. Overall uniformity for both lamps decreases with the increase in pole distance, and the HSPV lamp shows a slightly higher value of overall uniformity than the LED replacement lamp. From Fig. 6, we can see a reduction in longitudinal uniformity with an increase in pole distance. For the LED replacement lamp, the maximum pole distance is 25 m as compared to the HPSV lamp, 32 m (Fig. 6). When the pole distance is higher than 25 m (for LED) and higher than 32 m (for HSPV), the longitudinal uniformity is lower than the minimum value. This may be due to the loss in light output especially in regions between 60 and 90° as shown in the polar distribution diagram in Table 4 where we can see a shorter "wing". The threshold increment between both lamps is similar with a value of 3–4% as compared to the requirements for a maximum threshold increment of 10% (Fig. 7).

The percentage difference of the simulation parameter is shown in Fig. 8. The difference in average luminance between both types of lamp is consistent at 52% with the HPSV 150 W lamp having the higher value. The reduction can be attributed to the reduction in light output from the luminaire, which is 11,146 lm for the HPSV

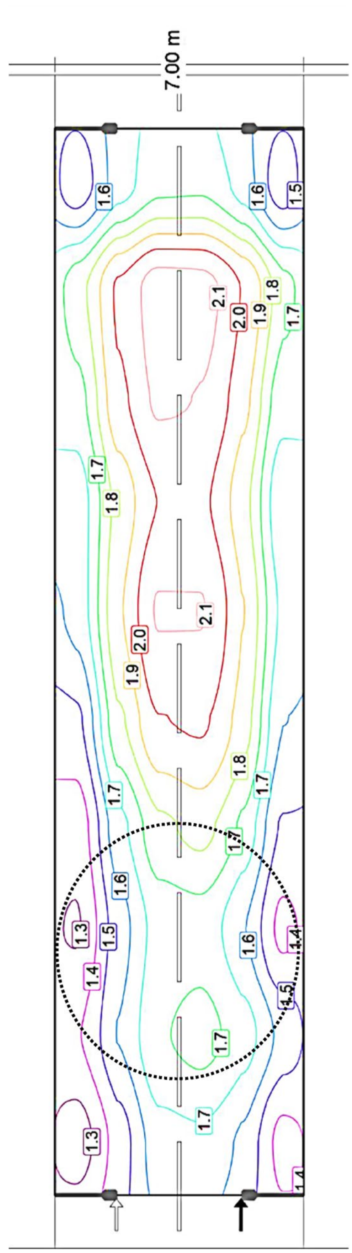


Fig. 2 Maintenance value, luminance with dry roadway [cd/m^2] (ISO-illuminance curves) from observer 1 using HPSV lamp

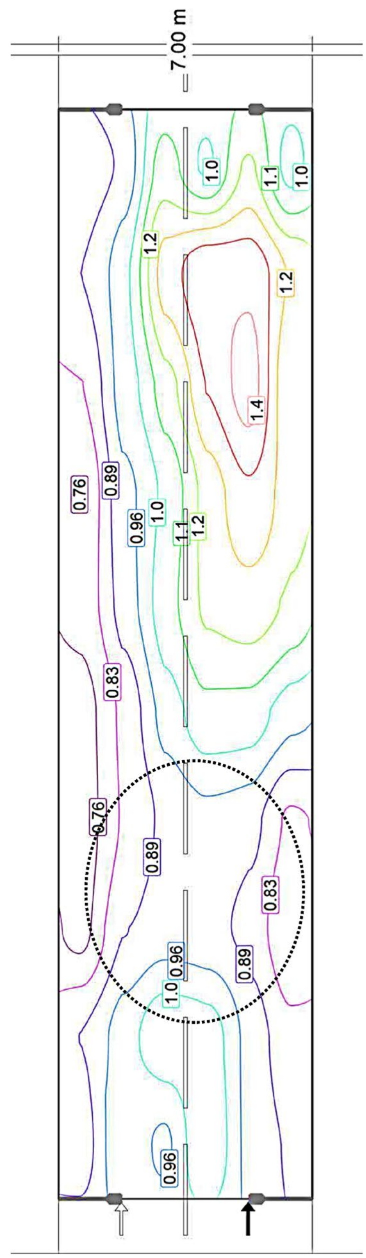


Fig. 3 Maintenance value, luminance with dry roadway [cd/m^2] (ISO-illuminance curves) from observer 1 using LED replacement lamp

Table 5 Lighting simulation results at a 30-m pole distance in comparison with the setting parameter from Table 2

	Target value	HPSV lamp	LED replacement lamp
Average luminance (cd/m^2)	≥ 1.5	1.71	0.83
Overall uniformity	≥ 0.4	0.75	0.71
Longitudinal uniformity	≥ 0.7	0.77	0.60
Threshold increment	≤ 10%	3%	3%

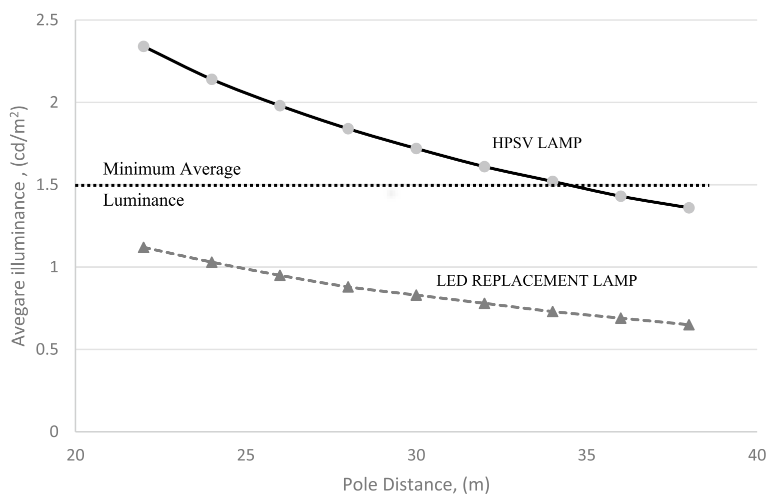


Fig. 4 Variation of average luminance L_{av} with pole distance. HPSV lamp is shown by the circle symbol whereas the LED replacement lamp is shown by the triangle symbol

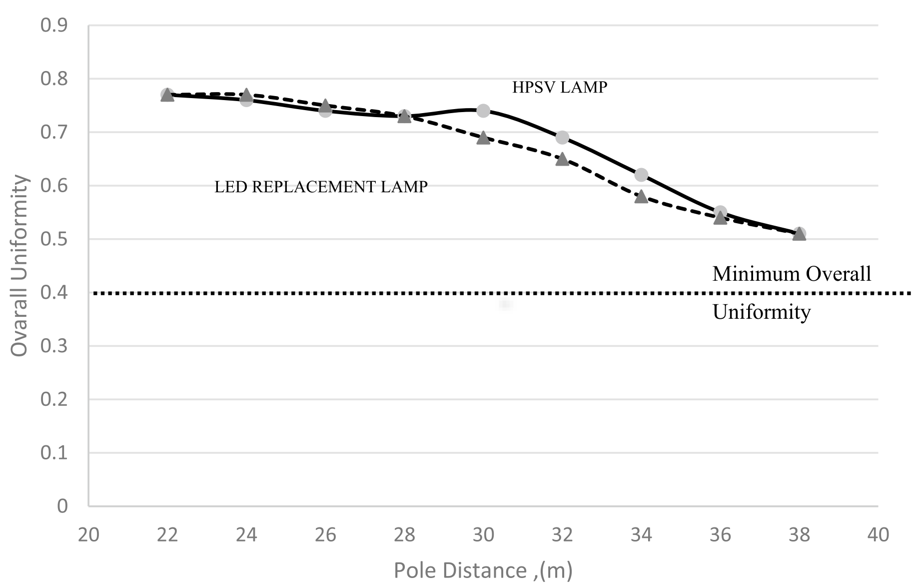


Fig. 5 Variation of overall uniformity with pole distance. HPSV lamp is shown by the circle symbol whereas LED replacement lamp is shown by the triangle symbol

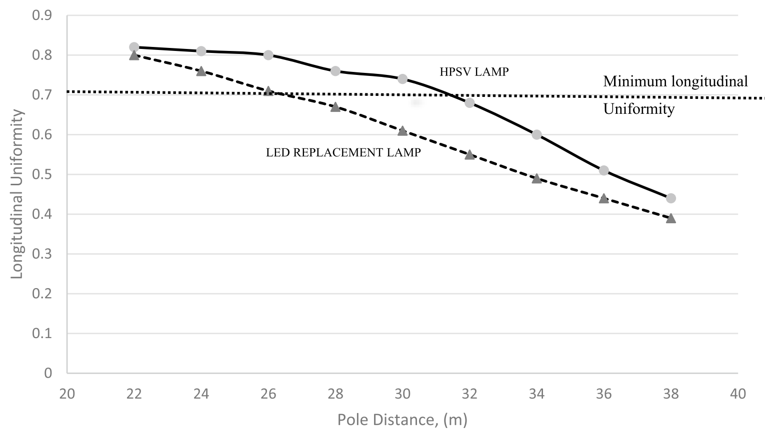


Fig. 6 Variation of longitudinal uniformity with pole distance. HPSV lamp is shown by the circle symbol whereas LED replacement lamp is shown by the triangle symbol

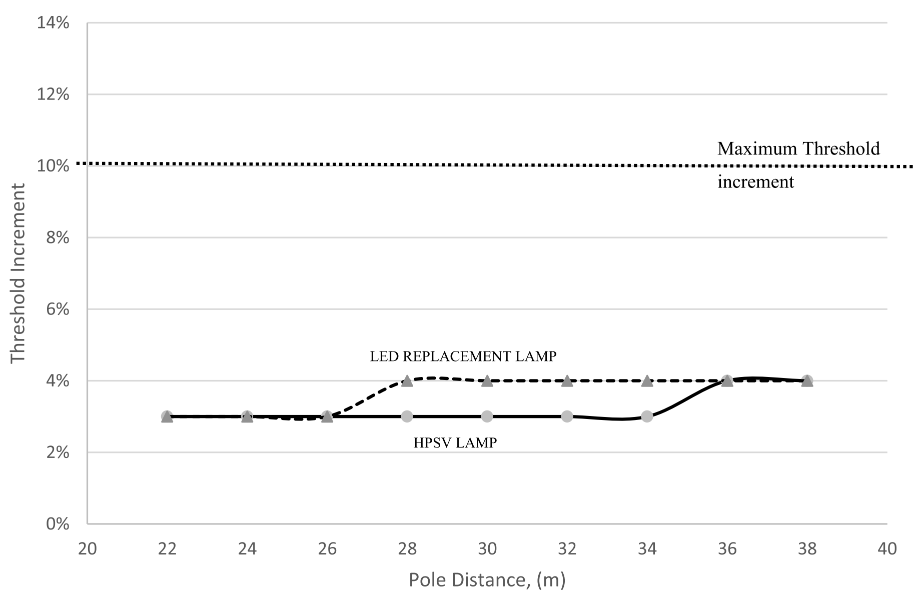


Fig. 7 Variation of threshold increment value with pole distance. HPSV lamp is shown by the circle symbol whereas LED replacement lamp is shown by the triangle symbol

luminaire as compared to 5161 lm for the LED replacement lamp. The average difference in overall uniformity is 2% (Fig. 8) which is a very minimal difference between the two lamp types. For the ME2 requirements, a uniformity of 0.4 is the minimum value for overall uniformity. Both HPSV and LED replacement lamps comply with this minimum value. By comparing both lamps, the largest percentage difference is the average luminance value (52%) while the least difference is the overall uniformity. The longitudinal uniformity shows a 2% difference for a short pole distance at 22 m in comparison with an 18% difference for pole distance at 32 m.

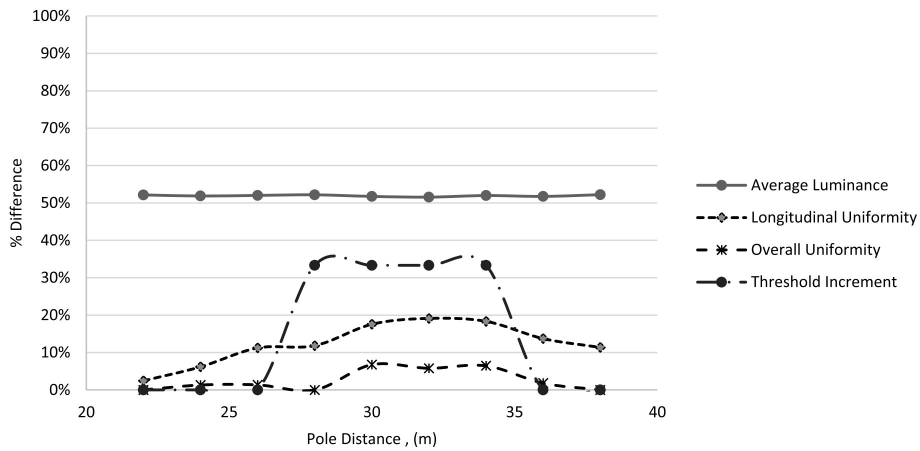


Fig. 8 Percentage difference of simulation parameter for various pole distances

Conclusions

In conclusion, the simulation study shows that replacing an HPSV lamp with a LED replacement lamp is an alternative method rather than replacing entire luminaires. Using more efficient lighting, such as LED at a lower cost, can be seen as a very promising solution. According to the lighting simulation results, we observe that the HPSV road light simulation has a higher luminance value than the LED replacement lamp with a reduction of 52%. There is no substantial difference in overall uniformity and longitudinal uniformity for short pole distances but increases for larger pole distances. It may be due to minimal change in the light distribution pattern as the original light fixture is used. A large reduction in luminance value is due to the large structure of the replacement lamp. Thus, local authorities and manufacturers should be careful in introducing such systems for actual road conditions. A thorough study of the replacement lamp for HPSV light fixtures should be carried out to prevent the reduction of required light output and affect the safety of the designed road. In the future, we will continue photometric studies for various HSPV and LED lamps to find the best solution for road lighting.

Abbreviations

HSPV High-pressure sodium vapor
LED Light-emitting diode
L_{av} Average luminance
U_o Overall uniformity
U_l Longitudinal uniformity
TI Threshold increment
ISO International Organization for Standardization

Acknowledgements

We acknowledge the Malaysian Public Works Department (JKR), Ministry of Education Malaysia, under FRGS grant (FRGS/1/2021/WAB02/USIM/02/1), and Universiti Sains Islam Malaysia (USIM) for the funding and support.

Authors' contributions

The experiment was done by M. H. J. and N. A. M. B., and major writing was done by M. H. J. W. Z. W. I. supervised the research, and E. M. H. co-supervised the research. All authors have read and approved the final manuscript.

Funding

Funding for this project is provided by the Malaysian Public Works Department (JKR), Malaysia.

Availability of data and materials

All data are presented in the manuscript.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 12 January 2023 Accepted: 14 September 2023
Published online: 30 September 2023

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