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Photometric Analysis of Filament Type LED Lamp for HPSV Lamp Substitution in Conventional Road Lighting Luminaires

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ABSTRACT

Energy reduction is a great challenge in road lighting applications. Replacing high-pressure sodium vapour (HPSV) with light emitting diode (LED), is a viable approach to reduce energy consumption. However, total replacement can incur a significant capital cost. To reduce the adoption costs, this study aims to investigate the effects towards light distribution of replacing HPSV lamps with filament LED lamps which has similar size and construction. Luminous Intensity Distribution (LID) curve measurement and Luminaire Classification System is used as comparison tools. Both lamps were installed into similar HPSV luminaires to assess photometric performance using goniophotometer measurements. Even though with similar light structure the location of the light output of the lamp caused change in the resulted light output distribution. Evaluation of the LCS diagram shows the luminaire has loss its forward and longitudinal throw of light output and has change to backward and narrow throw. The change is more significant on parabolic reflector of smaller structure. The bowl reflector of the light source and different structure of light output from lamp may have been the cause of this reduction.

Keywords: *High-pressure sodium vapour; light emitting diode; light intensity distribution curve; light output ratio; filament LED lamp*

1. Introduction

High-pressure sodium vapour (HPSV) lamp is currently used for road lighting in Malaysia due to its cheaper price. However, the current trend is moving towards energy efficient lighting such as Light Emitting Diode (LED) and plasma induction [1,2]. In 2015, EU has decided to phase out light source with hazardous material from 2021 to 2027 [3]. In the near future, current HPSV lamps might be phased out, unusable and replaced by more energy efficient light sources. Current method of using LED light source is a comprehensive conversion, which involves replacing the entire HPSV luminaire with a new complete LED luminaire which comes at a high upfront expense [4].

Another approach introduced by lamp manufacturers is by replacing the HPSV lamps with LED replacement lamps while maintaining the original HPSV luminaire housing [5]. An economic potential study Kovačević *et al.,* [5] regarding using LED Corn bulbs reveal positive economic potential with payback periods of 2 – 5 years [6]. Conversion of lamp is a common practice for indoor installations

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but rarely carried out in road lighting installation due to many safety requirements involving road lighting applications [7]. For road lighting or public lighting, sufficient illumination is required to reduce traffic accidents [8]. 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 [9]. LEDs are also superior to HPSV lamps in terms of visual acuity due to the higher colour rendering index (CRI) and visual capabilities. Studies have shown that a lower lumen output of LED lamp is sufficient to match higher lumen values form HPSV lamp [10]. In this study based on actual field measurements the author concluded that LED light source can replace HPSV lamps with reduced lumen factor of 1.46.

A recent study of using LED replacement lamps of LED corn bulb found that using a light source not designated for the fitting will cause changes in the light output and reduce efficiency of the fitting [11]. The author investigated the usage of LED corn bulbs as replacement lamp based on photometric performance. This research aims to study the filament LED lamps and HPSV lamps based on photometric methods in order to look at the suitability of the filament LED lamps in HPSV luminaire. Filament LED lamps have similar construction to HPSV lamps as opposed to LED corns bulbs of different structure. Thus, a photometric analysis of LED filament lamp and HPSV was implemented to observe the properties of light distribution and performance of both lamps. The changes of Light Intensity Distribution Curve (LIDC) can be observed for both lamps based on photometric measurement. This study focuses on luminous intensity distribution, luminous flux output and light output ratio of the luminaire using goniophotometric method and comparative analysis.

2. Methodology
2.1 Goniophotometric Measurement

This study incorporates goniophotometric lighting measurement and Luminous Intensity Distribution (LID) Curve to evaluate the suitability of Filament LED lamps as substitution for HPSV lamps. Figure 1 shows the flow chart of the method.

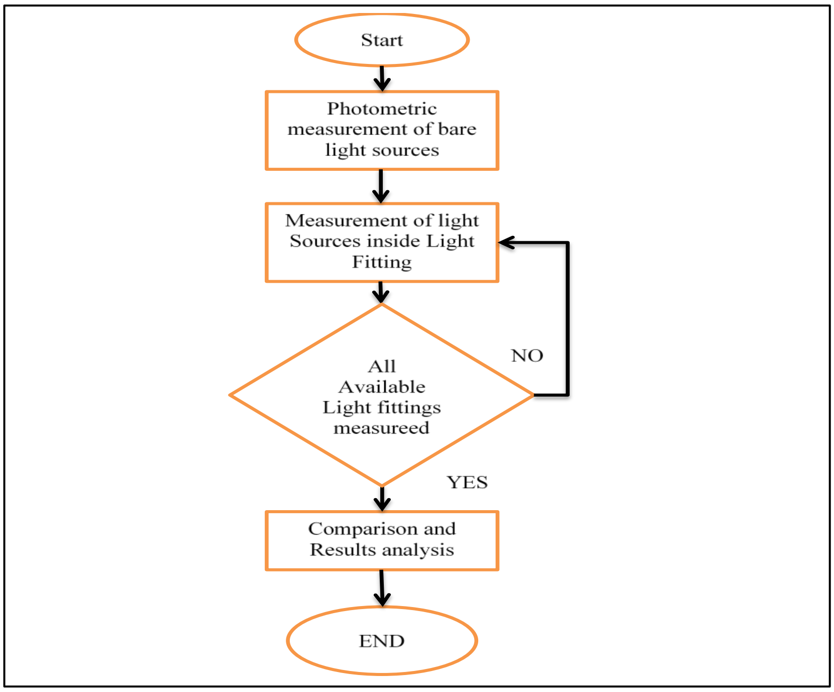


Fig. 1. Test method flow chart for relative photometry measurement

The comparison focuses mainly on the LID curve and LCS zonal classification evaluation. The test samples consist of HPSV lamp (150W) and Filament LED lamp (40W) as in Figure 2 (a), (b) where the 150 W HPSV lamp was used as the basis for analysis of the 40 W filament LED lamp. The 40 W filament LED lamp has multiple series-connected LEDs on a transparent substrate, referred to as chip-on-glass (COG). The light fixture for both types of lamps is similar, as shown in Figure 3

(a) (b)

LAMP TYPE	D	C
HPSV LAMP 150 W	47 mm	211 mm
FILAMENT LED LAMP 40 W	46 mm	225 mm

Fig. 2. Test sample, 150 W HPSV lamp (a) 40 W filament LED lamp (b) and its dimension

Two types of lamp fixture are used which are ASL C21 150W and Nikkon S419 150W. Both fixtures are of same rating but with different reflector design. The bowl reflector of Nikkon S419 is slight smaller thant Amat Sinar ASL C21. Image of both test fixtures are shown in Figure 3. To ensure stability and reliability of the measurement, this study was conducted in a laboratory environment at an ambient temperature of 25 ± 2°C

(a) (b)

Fig. 3. Test sample (a) Amat Sinar S21 (fitting 1) (b) Nikkon S1419 150W (fitting 2)

and relative air humidity of <50% with reference to standards CIE 121 :1996. Goniophotometric measurement was conducted using Rotating Luminaire Goniophotometer based on C-γ measurement coordinate system [12]. Evaluation of performance is based on relative photometry where the Lamp photometric measurement is conducted before conducting the luminaire with designated lamp type. Test matrix combination is shown in Table 1.

Table 1
Test matrix of lamp and HPSV fitting

FIXTURE TYPE	LAMP TYPE	
	HPSV LAMP	LED FILAMENT LAMP
AMAT SINAR ASL C21 (Fitting 1)	TEST 1A	TEST 1B
NIKKON S419 150W (ftting 2)	TEST 2A	TEST 2 B

2.2 Photometric analysis

Photometric evaluation mainly focuses on the luminous intensity distribution (LID) curve and light output ratio (LOR) as this study focuses on the photometric aspect regarding the replacement lamp. Analysis is based on relative photometric to analyze the capability of HPSV fittings in regard to different light source and construction. Thus, the main values for evaluation are the LOR and LID values.

LOR is calculated using the Eq. (1)

$$(LOR) = \frac{total\ luminous\ flux\ of\ luminaire}{Total\ Luminous\ Flux\ of\ Lamp} \tag{1}$$

Luminous intensity distribution curve comparison is based luminaire classification system zonal lumens using percentage of total luminous flux from each measurement, graphical display is shown in Figure 4. Photometric output is divided into 3 main zones which are Forward (F), Backward (B) and Upward (U). These zones are further detailed into Forward very high (FVH), Forward High (FH), Forward Medium (FM), Forward Low (FL) Backward Low (BL), Backward Medium (FM) Backward Medium (BM), Backward High (BH) and Backward Very High (BVH), Uplight Low (UL) ang Uplight High (UH).

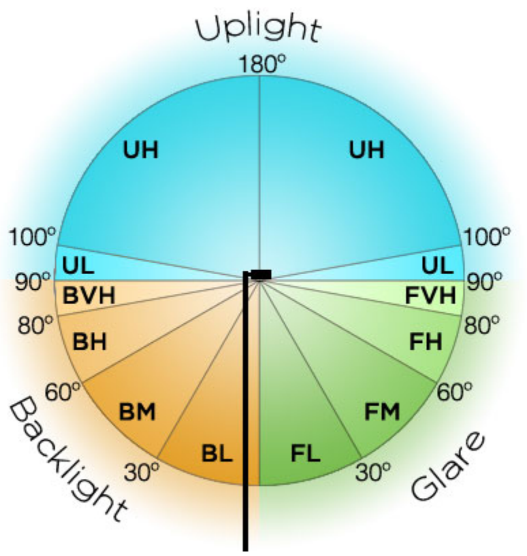


Fig. 4. Luminaire classification system zonal lumens [13]

3. Results and Analysis

3.1 Goniophotometric Measurement Results

Table 2 and Table 3 shows the light output ratio of of each HPSV fixture and it respective light source.

Table 2
Light output ratio of Amat Sinar ASL 150 W fitting with different light source

AMAT SINAR ASL21 150 W			
LIGHT SOURCE	AVERAGE LAMP LUMENS (lumens)	LUMINAIRE LUMENS (lumen)	LIGHT OUTPUT RATIO (LOR)
OSRAM 150 W HPSV LAMP	15200	12033	79.20%
PHILIPS TRUEFORCE CORE 40W FILAMENT LED LAMP	7500	5344	71.30%

Table 3
Light output ratio of NIkkon 150 W fitting with different light source

NIKKON S419 150W			
LIGHT SOURCE	AVERAGE LAMP LUMENS (lumens)	LUMINAIRE LUMENS (lumen)	LIGHT OUTPUT RATIO (LOR)
OSRAM 150 W HPSV LAMP	15200	10953	73.00%
PHILIPS TRUEFORCE CORE 40W FILAMENT LED LAMP	7500	4305	57.40%

Based on Table 2 and Table 3, both fittings show a reduction in light output ratio when using the Filament LED lamp in fixture 1 the reduction is approximately 8 % while in fixture 2 shows a reduction of 25.7 %.

3.2 Luminaire Classification System Zonal Lumens

Table 4 and Table 5 shows the LCS Zonal lumens for Amat Sinar S21 (fixture 1) and Nikkon S419 (fixture 2) using 150 W HPSV lamp and 40 W Filament LED Lamp [14]. From Table 3 and Table 4 it can be observed that there is reduction of luminaire lumens from FM, FH angles while an increase at BL and BH angle. Light throw has shifted from a forward throw to a backwards throw. This shift can be seen from the Luminous intensity distribution diagram as in Figure 5 and Figure 6.

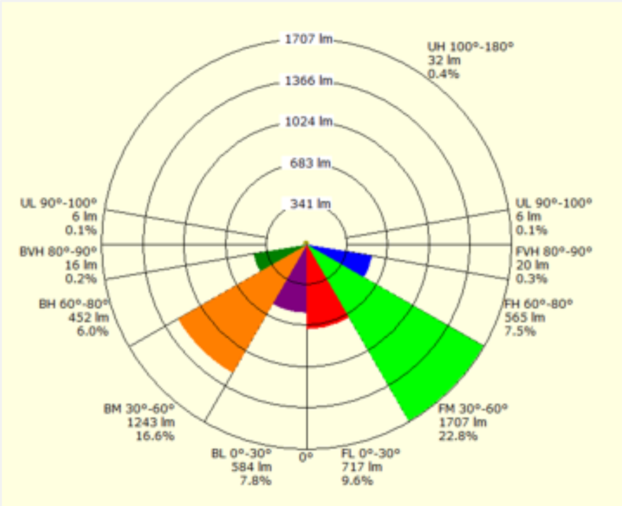
Similar findings were also found in Nikkon S419 fixture which is more significant. Percentage ratio of luminaire lumens in FM and FH angle decrease from 29.5 % to 26.0% and 9.3% to 7.8 % respectively. Percentage ratio of Luminaire lumens in BL and BH angles increased from 13.2 % to 13.8 % and 26.1 % to 31.4 % respectively. Fixture 2 has a smaller bowl reflector size than fixture 1 which have may have been the cause of large reduction in light output.

Table 4
LCS zonal lumen Amat Sinat S21 150 W

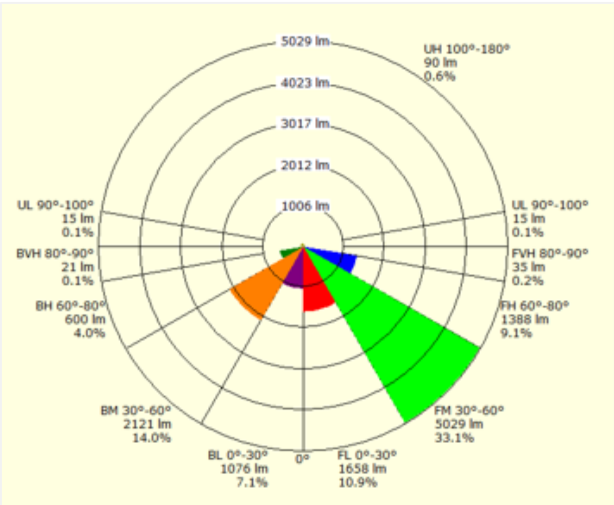
	150 W HPSV LAMP		40 W FILAMENT LED LAMP	
	% Lamp Lumen	% Luminaire Lumens	% Lamp Lumen	% Luminaire Lumens
FL (0°-30°)	10.9%	13.8%	9.6%	12.1%
FM (30°-60°)	33.1%	41.8%	22.8%	28.8%
FH (60°-80°)	9.1%	11.5%	7.5%	9.5%
FVH (80°-90°)	0.2%	0.3%	0.3%	0.4%
UL (90°-100°)	0.1%	0.1%	0.1%	0.1%
UH (100°-180°)	0.6%	0.8%	0.4%	0.5%
BL (0°-30°)	7.1%	9.0%	7.8%	9.8%
BM (30°-60°)	14.0%	17.7%	16.6%	21.0%
BH (60°-80°)	4.0%	5.1%	6.0%	7.6%
BVH (80°-90°)	0.1%	0.1%	0.2%	0.3%
TOTAL	79.2%	100.0%	71.3%	100.0%

Table 5
Light LCS zonal lumens NIkkon S419 150W (fixture 2)

	150 W HPSV LAMP		40 W FILAMENT LED LAMP	
	% Lamp Lumen	% Luminaire Lumens	% Lamp Lumen	% Luminaire Lumens
FL (0°-30°)	10.4%	14.3%	7.4%	12.9%
FM (30°-60°)	21.5%	29.5%	14.9%	26.0%
FH (60°-80°)	6.8%	9.3%	4.5%	7.8%
FVH (80°-90°)	0.5%	0.7%	0.4%	0.7%
UL (90°-100°)	0.2%	0.3%	0.1%	0.2%
UH (100°-180°)	0.6%	0.8%	0.4%	0.7%
BL (0°-30°)	9.6%	13.2%	7.9%	13.8%
BM (30°-60°)	19.0%	26.1%	18.0%	31.4%
BH (60°-80°)	4.1%	5.6%	3.6%	6.3%
BVH (80°-90°)	0.2%	0.3%	0.2%	0.3%
TOTAL	79.2%	100.0%	57.4%	100.0%

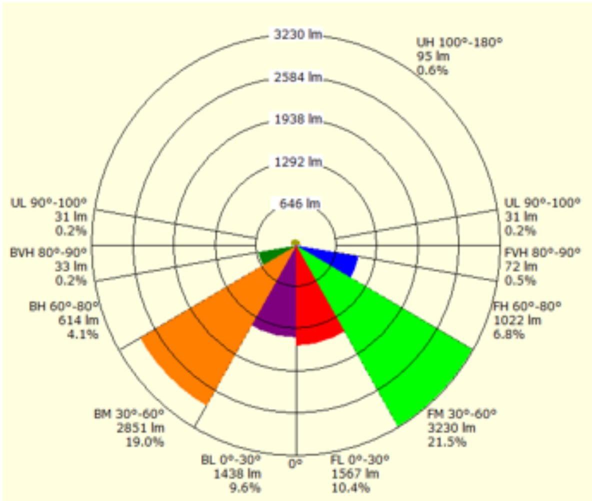


Test 1A

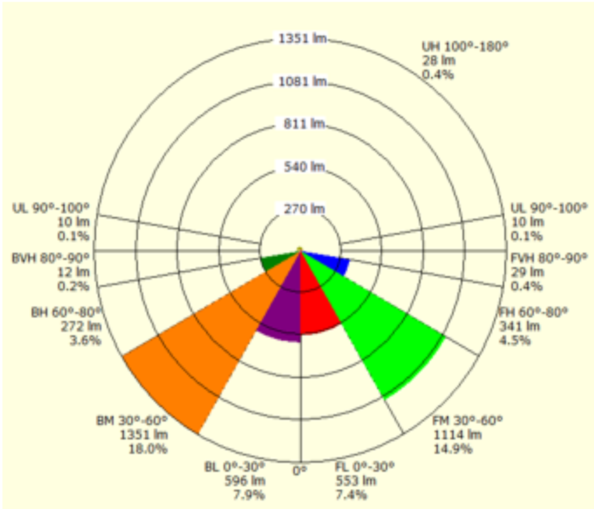


Test 1B

Fig. 5. LCS diagram for HPSV lamp (Test 1A) and filament LED lamp (Test 1B) in Amat Sinar S21 150W fixture



Test 2A



Test 2B

Fig. 6. LCS diagram for HPSV lamp (left) and filament LED lamp (right) in NIKKON S419 150W fixture

4. Conclusions

In this study, goniophotometric measurement and analysis were conducted on filament type LED Lamps as HPSV replacement lamps. Two different type of conventional road lighting luminaires were used to evaluate the photometric performance and feasibility as replacement lamps to reduce the energy consumption with added benefit of LED lighting system. According to the photometric results when the HPSV lamp fixture was retrofitted with the Filament LED lamp source resulted in reduction in luminaire performance and change in the light distribution patter. The luminaire's performance is reduced to a 71.3% light output ratio (LOR) from 79.2 % for fixture 1 and 57.4 % LOR form initial LOR of 79.2 % for fixture 2.

Even though with similar light structure two different results were acquired for light output distribution. Evaluation of the polar diagram shows the luminaire has loss its forward and longitudinal throw of light output and has change to backward and narrow throw. The change is more significant on parabolic reflector of smaller structure for fixture 2. The bowl reflector of the light source and different structure of light output from lamp may have been the cause of this reduction. cause of this reduction. Thus, local authorities and manufacturers should evaluate the luminous intensity distribution output when introducing such systems in actual road conditions.With advancement in LED replacement technology and studies on lower luminance lighting in the mesopic range, utilization of replacement lamps might be of viable method.

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