TEEAM

The Electrical and Electronics Association of Malaysia

TECHNICAL REPORT

SUITABILITY OF LED FOR ROAD LIGHTING IN MALAYSIA

EDITION 1

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CONTENTS

FOREWORD

This Technical Report was developed by the Working Group on LED for Road Lighting under the authority of The Electrical and Electronics Association of Malaysia (TEEAM).

This Technical Report gives recommendations on the suitability of LED for road lighting in Malaysia with the justification based on a comprehensive techno-economic analysis of the current best available technology LED and HPSV lighting systems and with public safety in mind.

This Technical Report is the first edition and will be reviewed every 4 to 6 months depending on the development in LED technologies.

EXECUTIVE SUMMARY

This Working Group was established to study the suitability of Light Emitting Diode (LED) light source for road lighting at this moment of its technological development, in response to the call of many stakeholders in the road lighting industry who are extremely concerned that untimely rush into use of this technology may cost the federal government, state government, local government and highway operators, dearly in providing safe road lighting and this cost will ultimately be passed back to all Malaysians in the form of direct and indirect taxes and higher toll charges. They are also concerned that there is no proper detailed cost and benefit justification and comparison with the best of existing proven technology, thus creating an unhealthy situation that is open to abuse by unscrupulous opportunists for their own benefit at the expense of the general public.

At this stage of LED development, the conclusion of this study is as follows.

	Advantage of using LED	For 3-lane dual carriageway (ME1 lighting class)	For 4-lane bi-directional carriageway (ME2 lighting class)
1) Energy saving	No	LED use 15% more power	LED use 10% more power
2) Cost saving	No	Increase initial cost by 5 times with LED products	Increase initial cost by 2 times with LED products
3) Maintenance cost over 20 years	No	12.5 times more with LED products	5 times more with LED products
4) Safety and security	No	Impact of LED on road lighting is still under deliberation. Current lighting standards have to be respected, or public safety will be compromised.	
5) Environmental impact	No	5 times more using LED products	2 times more using LED products

The result of this study can be corroborated with similar studies carried out by Kostic, M. et al. – 'LEDs in Street and Ambient Lighting – Two case studies' enclosed with this report as Appendix A, and by Onaygil, S. et al titled 'Cost Analysis of LED Luminaires in Road Lighting' which is enclosed herewith as Appendix B, for European climatic condition which is less taxing.

The Maintenance Factor (MF) for LED luminaire used in this study is calculated using the method presented by LacBatel, C., Sergent, M. in their paper titled

'Maintenance Factor Of Outdoor LED Lighting Installation' enclosed herewith as Appendix C. The MF value of 0.717 obtained is at best a good estimate, thus risking a possibility of more life cycle cost if this figure is on the high side. On the other hand, the MF of 0.8 in the scenario presented here for HPSV solution is well established, and maintenance budget can be easily allocated accurately to ensure that the safe lighting level is always maintained. The MF for LED and HPSV solution for the same luminaire cleaning interval is not the same. Detail on MF is on page 3 to 5 of this report. Henceforth, the initial lighting level of LED has to be higher than that of HPSV solution.

The non-professional current practice of having administrators to view visually a new lighting installation and make policy decision based on his feel is wrong and must be stopped.

It is also established herewith that the efficiency of a lighting solution does not depend solely on the efficacy of the light source alone. Other influencing parameters have to be taken into consideration and fortunately well tested software tools are already widely available to make the calculation.

Up to 9% of energy can be saved by just cleaning the luminaire every year and up to 25% of energy saving can be achieved over the lamp lifespan by using Constant Light Output (CLO) gears or controller. (CLO for HPSV is attached in Appendix D). Finally, during period of low traffic, up to 20% energy can be saved. **Just by improving on our current practice of designing, operating and maintaining a road lighting installation, a total of up to 54% energy saving can easily be achieved**.

In this study, on page 11, Table 3, it is also shown that there was also a lot of improvement in the photometry of HPSV luminaires that an old installation using 400W luminaire can be replaced with current high performance 250W HPSV luminaire on a one to one basis without having to shift the position of the poles. This upgrading results in an immediate energy saving of 40%.

Zhaga which is an industry wide consortium is in the process of developing industry standard specifications for LED light engine to ensure interchangeability of light engine from different manufacturers, provide a stable design platform for luminaire makers and to future-proof light engines which can be second sourced and upgraded. As Zhaga is an industry wide consortium, standard specifications develop by Zhaga will become international standard. Luminaire in the market now are not Zhaga compliant and will be obsolete soon, thus becoming a maintenance nightmare in terms of availability of spare parts.

LED is still evolving at a fast rate even at this moment and will eventually become viable as alternative lighting solution for road lighting. For this reason, this Working Group will review the situation periodically and advise accordingly on the readiness of LED as a good viable alternative lighting solution for road lighting. Meanwhile, use of LED for road lighting must be assessed carefully to ensure lower total life cycle cost and environmental impact than the existing technology. The approach used in this study is a simple method to do so.

SUITABILITY OF LED FOR ROAD LIGHTING IN MALAYSIA

1 Background

In the last few years, Light Emitting Diode (LED) has been marketed aggressively as the light source that can replace all the lamps that are now in common use claiming that it is energy efficient, long life and green. In this time of unprecedented green movement, this has put a lot of pressure on policy makers who are obliged to reduce carbon emission and at the same time attracts opportunists out to capitalize from this huge green bandwagon. However, experience with LED products for road lighting has so far been generally negative especially the long life or reliability aspect. Technical data of LED for road lighting did not indicate that LED is any more efficient than other highly efficient lamps that are much cheaper, widely used and easily available in the market. As such, involvement of government in promoting the use of LED for road lighting using public fund without proper detailed cost and benefit justification need to be reviewed urgently.

Under such circumstances, The Electrical and Electronic Association of Malaysia (TEEAM), which is in the forefront in promoting green, is taking the initiative to study the use of LED in areas of public interest. The formation of the Working Group involving all interested parties to study the suitability of LED for road lighting is one of such initiative.

This Working Group is established to evaluate the suitability of LED light source for road lighting as this area of lighting is of immense public importance as it involves

(a) the safety and security of road users,
(b) the use of public funds to provide, maintain and operate road lighting systems, and
(c) the environmental impact to the manufacture, distribution, use and finally disposal of lighting equipments and consumables.

This Working Group is made up of members from professionals, manufacturers, operators and other stakeholders in this area of lighting and this report is open to the public to study, dissect, evaluate and comment on its accuracy and conclusion, after which, to be used as a guide/reference for evaluation of light sources for road lighting so that investment in this area of lighting is based on sound technical and financial considerations and not on loosely defined criteria such as the widely abused word “green”.

2 Introduction

During the recent CIE 27th Session that took place from 11th to 15th July 2011 in Sun City, South Africa, two papers on similar subject were presented. Kostic, M. et al. of the University of Belgrade presented a comprehensive techno-economic analysis of using LED for road and ambient lighting regarding **efficiency, maintenance and financial aspects based on the frequently declared economic life of LED of 50,000 hours with lumen depreciation factor of 0.8 (L80), conclude that LEDs are not yet appropriate for road lighting**. The full report is as shown in **Appendix A**. The other paper as attached in **Appendix B**, by Onagyil, S. et al. on Cost Analysis of LED Luminaires in Road Lighting based on the economic life of 30,000 and 50,000 hours for LEDs, concludes that LED Luminaires can be feasible only if it has higher efficacy and lower cost than recent situation. In other words, it is not feasible now.

This Working Group evaluates the suitability of LED light source for use in road lighting as compared to the present, widely used High Pressure Sodium Vapour (HPSV) Light source from the energy, long life and environmental impact aspects in the Malaysian situation. In making the comparisons, latest technological development in both are used to comply with the Malaysian Code of Practice (**COP**) for the Design of Road Lighting, **MS 825, 2007**. LED is basically another type of light source and compliance with the COP will ensure that the objectives of the specified lighting task, especially the safety of road users, are met. Appropriate factors are taken into consideration to allow direct comparison and where direct comparison is not possible, cost argument is used instead.

3 Energy comparison of HSPV and LED luminaires

The energy comparison is made with luminaires from major players in road lighting, one from US, two from Europe, one from China and compare to a HPSV luminaire made in Malaysia. The calculation is made from photometric data from the manufacturers using the Ulysse software (version 2.1) developed by Schréder specifically for road lighting simulation. In the case of the luminaire from China where photometric data is not downloadable from the website, the calculation is from their published data.

The comparisons are made for two typical types of road geometry that are very common in Malaysia, namely 3-lane dual carriageway to be lit to ME1 lighting class and 4-lane single carriageway, bi-directional traffic to be lit to ME2 lighting class. For the 3-lane dual carriageway, comparisons are made for twin central installation and opposite installation. For the 4-lane single carriageway, calculations are done for opposite, opposite staggered, and single sided installation.

The maintenance factor (MF) used in Malaysia for HPSV luminaires has been standardized at 0.8 and luminaire of IP6X are now generally used. For the purpose of this study, we assume that luminaire cleaning is done during re-lamping and these roads are generally in medium pollution category. This works out to be about 4 years or 17520 hours based on 12 hours operation per night. Figure 1 shows the lumen maintenance and survival rate of high output, 4 year HPSV lamp. Table 1 shows the Luminaire Maintenance Factor (LMF) for an IP6X luminaire [MS 825: Part 1: 2007]. The MF for HPSV luminaire is the product of lumen output after 4 year operation and LMF at 4 years which works out to be 0.8. During this period before scheduled relamping, 8% (or average of 2% per year) of lamps MAY fail and have to be attended to immediately in order to comply with the safe lighting standard and the cost is accordingly taken into consideration in the calculation of maintenance cost. As such, the Lamp Survival Factor (LSF) for road lighting is not applicable [CIE 154: 2003].

Figure 1. Lamp lumen maintenance and survival rate (Philips SON-T PIA PLUS)

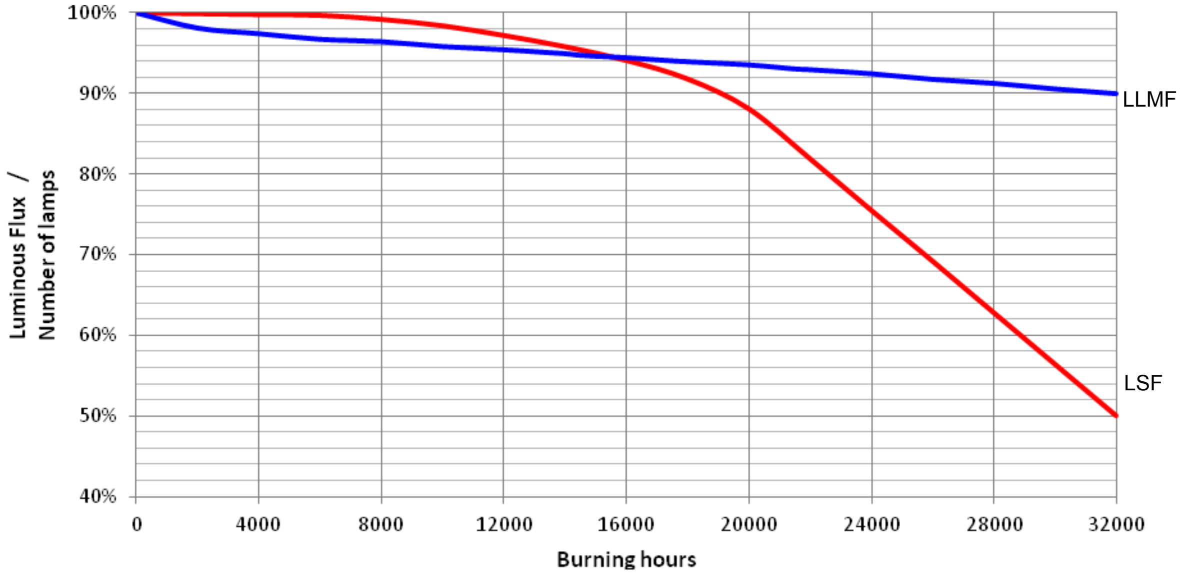


Table 1. Luminaire maintenance factor (MS 825 : Part 1 : 2007)

Cleaning interval	Luminaire maintenance factor								
	IP2X minimum [a]			IP5X minimum [a]			IP6X minimum [a]		
months	High pollution[b]	Medium pollution[c]	Low pollution[d]	High pollution[b]	Medium pollution[c]	Low pollution[d]	High pollution[b]	Medium pollution[c]	Low pollution[d]
12	0.53	0.62	0.82	0.89	0.90	0.92	0.91	0.92	0.93
18	0.48	0.58	0.80	0.87	0.88	0.91	0.90	0.91	0.92
24	0.45	0.56	0.79	0.84	0.86	0.90	0.88	0.89	0.91
36	0.42	0.53	0.78	0.76	0.82	0.88	0.83	0.87	0.90

[a] Ingress protection code number of lamp housing; see BS EN 60529.
[b] High pollution generally occurs in the centre of large urban areas and heavy industrial areas.
[c] Medium pollution generally occurs in semi-urban, residential and light industrial areas.
[d] Low pollution generally occurs in rural areas.

The construction of LED luminaire is different from that of a HPSV luminaire and the MF has to consider other depreciating factors. For this, we shall use the tool to calculate MF for LED as presented by Lac-Batel, C. and Sergent, M., Lighting Application Specialists of Philips Lighting, during the 27th CIE Session. Their paper is as shown in **Appendix C**. The MF for a LED luminaire with PMMA lens, driven at

350mA, in our average ambient temperature of 28°C, with same cleaning interval of 4 years in medium pollution environment works out to be 0.717. The calculation is given below.

Calculation of maintenance factor for LED street lighting installation:

The maintenance factor for LED street lighting installation is derived based on the methodology and data presented in Appendix C.

i) Lamp Lumen Maintenance Factor (LLMF):

LLMF	=	*Lumen depreciation for 25°C ambient temperature (0.936)*	*x*	*Lumen depreciation for driving current of 350mA (0.934)*	*x*	*Relative initial flux at 28°C (0.992)*
LLMF	=	*0.867*				

ii) Luminaire Maintenance Factor (LMF):

LMF	=	*Luminaire depreciation factor for medium pollution environment & cleaning intervals of 4 years (0.841)*	*x*	*Aging of PMMA optical lenses (0.983)*
LMF	=	*0.827*		

iii) MF = LLMF (0.867) x LMF (0.827)

MF = 0.717

From the foregoing explanation, the MF for HPSV based on 4 year cleaning cycle and re-lamping is 0.8 and for LED is 0.717. Table 2a shows the comparison for a 3-lane dual carriageway, lit to ME1 lighting class, twin central installation and Table 2b shows that of the same highway with opposite installation. Table 2c shows comparison for a 4-lane single carriageway, 2 lanes per traffic direction, lit to ME2 lighting class, with opposite installation, Table 2d for opposite staggered installation and Table 2e for single sided installation. The simulation is optimized for energy efficiency.

Table 2a. Comparison for ME1 lighting class – Twin central installation

Road Details								
1) Carriageway		Dual carriageway						
2) Road width		3 x 3.65m / carriageway						
3) Median		2m						
4) Road surface		R3 ; Qo = 0.07						
Installation Details								
1) Lighting system		LED				HPSV		
2) Luminaire type		USA	Europe-1	Europe-2	China	Malaysia		
3) Lamp power	(W)	204	-	215	-	150	250	400
4) System wattage (α)	(W)	237	256	228	275	176	285	450
5) Total luminous flux (lamp)	(klm)	15.6	29.9	23.4	23.0	17.5	33.2	56.5
6) Luminaire efficiency	(%)	100.0	82.8	72.0	-	81.0	80.5	82.4
7) Luminaire efficacy	(lm/W)	65.8	96.7	73.9	-	80.5	93.8	103.5
8) Lamp colour temperature	(K)	4000	4000	4250	-	2000	2000	2000
9) Pole arrangement		Twin central				Twin central		
10) Mounting height	(m)	12	12	12	12	12	12	15
11) Pole spacing (β)	(m)	21	34	26	29	26	40	69
12) Setback of pole	(m)	1	1	1	1	1	1	1
13) Overhang	(m)	1	0	1	-1	2	-1	2
14) Arm length	(m)	2	1	2	0	3	0	3
15) Arm inclination		0°	5°	0°	5°	5°	5°	5°
16) Maintenance factor		0.717	0.717	0.717	0.717	0.8	0.8	0.8
Lighting Performance								
1) Lighting criteria	Required level							
a) Average luminance	Lave ≥ 2cd/m^2	2.00	2.01	2.04	2.00	2.00	2.01	2.07
b) Overall uniformity	Uo ≥ 40%	44.4	43.2	44.2	40	42.2	41.7	41.1
c) Longitudinal uniformity	UL ≥ 70%	85.9	77.3	88.8	90.0	86.6	79.4	72.5
d) Threshold increment	TI ≤ 10%	4.1	6.9	8.9	10	8.8	9.9	10.0
e) Surround ratio	SR ≥ 0.5	0.5	0.5	0.5	0.9	0.5	0.6	0.6
2) Limitation factor		Lave	Lave	Lave	Lave	Lave	Lave	TI
Power Consumption								
1) Energy used per unit area { = α / (3 x 3.65 x β) }	(W/m^2)	1.03	**0.69**	0.80	0.87	0.62	0.65	**0.60**
2) Energy efficiency (benchmark against HPS)	(%)	-71.67	-15.00	-33.33	-45.00	-3.33	-8.33	0.00
3) Energy consumption per hour / km	(kWh)	22.57	15.06	17.54	18.97	13.54	14.25	13.04
4) Energy consumption per year / km	(kWh)	98,863	65,958	76,818	83,069	59,298	62,415	57,130

Note:

1) In the case where luminaire is measured using total flux method, the luminaire efficiency is given as 100% with the total lumen output of luminaire equal to the lamp luminous flux quoted above.

Table 2b. Comparison for ME1 lighting class – Opposite installation

Road Details								
1) Carriageway			Dual carriageway					
2) Road width			3 x 3.65m / carriageway					
3) Median			2m					
4) Road surface			R3 ; Qo = 0.07					
Installation Details								
1) Lighting system			LED			HPSV		
2) Luminaire type			USA	Europe-1	Europe-2	Malaysia		
3) Lamp power		(W)	204	-	215	150	250	400
4) System wattage (α)		(W)	237	256	228	176	285	450
5) Total luminous flux (lamp)		(klm)	15.6	29.9	23.4	17.5	33.2	56.5
6) Luminaire efficiency		(%)	100.0	82.6	71.2	81.0	82.7	83.6
7) Luminaire efficacy		(lm/W)	65.8	96.5	73.1	80.5	96.3	105.0
8) Lamp colour temperature		(K)	4000	4000	4250	2000	2000	2000
9) Pole arrangement			Opposite			Opposite		
10) Mounting height		(m)	10	10	12	12	12	15
11) Pole spacing (β)		(m)	20	34	27	24	40	64
12) Setback of pole		(m)	1	1	1	1	1	1
13) Overhang		(m)	1	1	2	2	2	2
14) Arm length		(m)	2	2	3	3	3	3
15) Arm inclination			5°	5°	5°	5°	5°	5°
16) Maintenance factor			0.717	0.717	0.717	0.8	0.8	0.8
Lighting Performance								
1) Lighting criteria	Required level							
a) Average luminance	Lave ≥ 2cd/m^2		2.02	2.03	2.02	2.01	2.04	2.02
b) Overall uniformity	Uo ≥ 40%		66.7	60.4	50.2	54.0	43.6	40.7
c) Longitudinal uniformity	UL ≥ 70%		82.7	75.2	88.4	86.1	71.5	75.4
d) Threshold increment	TI ≤ 10%		7.1	9.6	8.1	9.9	8.3	9.4
e) Surround ratio	SR ≥ 0.5		0.5	0.5	0.5	0.6	0.6	0.6
2) Limitation factor			Lave	Lave	Lave	Lave	Lave	Lave
Power Consumption								
1) Energy used per unit area { = α / (3 x 3.65 x β) }		(W/m^2)	1.08	**0.69**	0.77	0.67	0.65	**0.64**
2) Energy efficiency (benchmark against HPS)		(%)	-68.75	-7.81	-20.31	-4.69	-1.56	0.00
3) Energy consumption per hour / km		(kWh)	23.70	15.06	16.89	14.67	14.25	14.06
4) Energy consumption per year / km		(kWh)	103,806	65,958	73,973	64,240	62,415	61,594

Note:
1) In the case where luminaire is measured using total flux method, the luminaire efficiency is given as 100% with the total lumen output of luminaire equal to the lamp luminous flux quoted above.

Table 2c. Comparison for ME2 lighting class – Opposite installation

Item	Unit / Required level							
Road Details								
1) Carriageway		Single carriageway						
2) Road width		4 x 3.65m (2 lanes per traffic direction)						
3) Median		-						
4) Road surface		R3 ; Qo = 0.07						
Installation Details								
1) Lighting system		LED				HPSV		
2) Luminaire type		USA	Europe-1	Europe-2	China	Malaysia		
3) Lamp power	(W)	204	-	211	-	150	250	400
4) System wattage (α)	(W)	237	180	224	245	176	285	450
5) Total luminous flux (lamp)	(klm)	16.0	19.5	22.9	20.5	17.5	33.2	56.5
6) Luminaire efficiency	(%)	100.0	85.9	72.1	-	84.2	82.4	83.6
7) Luminaire efficacy	(lm/W)	67.5	93.1	73.7	-	83.7	96.0	105.0
8) Lamp colour temperature	(K)	4000	4000	4250	-	2000	2000	2000
9) Pole arrangement		Opposite				Opposite		
10) Mounting height	(m)	12	12	12	12	15	15	15
11) Pole spacing (β)	(m)	37	45	44	35	46	59	54
12) Setback of pole	(m)	1	1	1	1	1	1	1
13) Overhang	(m)	1	-1	-1	-1	2	1	2
14) Arm length	(m)	2	0	0	0	3	2	3
15) Arm inclination		5°	0°	0°	5°	5°	5°	5°
16) Maintenance factor		0.717	0.717	0.717	0.717	0.8	0.8	0.8
Lighting Performance								
1) Lighting criteria	Required level							
a) Average luminance	Lave≥1.5cd/m²	1.52	1.50	1.52	2.2	1.50	1.50	2.98
b) Overall uniformity	Uo ≥ 40%	53.0	61.8	56.7	60.0	44.5	51.3	49.5
c) Longitudinal uniformity	UL ≥ 70%	72.5	75.7	71.4	90	73.9	71.5	74.6
d) Threshold increment	TI ≤ 10%	6.2	9.9	10.0	10.0	9.8	10.0	10.0
e) Surround ratio	SR ≥ 0.5	0.5	0.7	0.5	0.7	0.5	0.7	0.6
2) Limitation factor		Lave	Lave,TI	Lave,TI	TI	Lave	Lave,TI	TI
Power Consumption								
1) Energy used per unit area { = α / (2 x 3.65 x β) }	(W/m^2)	0.88	**0.55**	0.70	0.96	**0.52**	0.66	1.14
2) Energy efficiency (benchmark against HPS)	(%)	-69.23	-5.77	-34.62	-84.62	0.00	-26.92	-119.23
3) Energy consumption per hour / km	(kWh)	12.81	8.00	10.18	14.00	7.65	9.66	16.67
4) Energy consumption per year / km	(kWh)	56,111	35,040	44,596	61,320	33,517	42,315	73,000

Note:
1) In the case where luminaire is measured using total flux method, the luminaire efficiency is given as 100% with the total lumen output of luminaire equal to the lamp luminous flux quoted above.

Table 2d. Comparison for ME2 lighting class – Opposite staggered installation

Road Details								
1) Carriageway			Single carriageway					
2) Road width			4 x 3.65m (2 lanes per traffic direction)					
3) Median			-					
4) Road surface			R3 ; Qo = 0.07					
Installation Details								
1) Lighting system			LED			HPSV		
2) Luminaire type			USA	Europe-1	Europe-2	Malaysia		
3) Lamp power		(W)	204	-	211	150	250	400
4) System wattage (α)		(W)	237	192	224	176	285	450
5) Total luminous flux (lamp)		(klm)	15.6	16.8	22.9	17.5	33.2	56.5
6) Luminaire efficiency		(%)	100.0	88.8	72.0	82.0	81.0	83.6
7) Luminaire efficacy		(lm/W)	65.8	77.7	73.6	81.5	94.4	105.0
8) Lamp colour temperature		(K)	4000	4000	4250	2000	2000	2000
9) Pole arrangement			Opposite Staggered			Opposite Staggered		
10) Mounting height		(m)	12	12	12	12	15	15
11) Pole spacing (β)		(m)	39	44	50	48	76	84
12) Setback of pole		(m)	1	1	1	1	1	1
13) Overhang		(m)	2	1	2	2	1	2
14) Arm length		(m)	3	2	3	3	2	3
15) Arm inclination			0°	5°	0°	5°	5°	5°
16) Maintenance factor			0.717	0.717	0.717	0.8	0.8	0.8
Lighting Performance								
1) Lighting criteria	Required level							
a) Average luminance	Lave≥1.5cd/m^2		1.53	1.50	1.55	1.50	1.51	2.13
b) Overall uniformity	Uo ≥ 40%		51.2	49.7	41.8	41.3	41.8	40.1
c) Longitudinal uniformity	UL ≥ 70%		71.1	83.2	70.0	78.3	77.3	71.1
d) Threshold increment	TI ≤ 10%		5.4	6.9	9.7	9.7	9.8	10.0
e) Surround ratio	SR ≥ 0.5		0.5	0.5	0.5	0.5	0.5	0.6
2) Limitation factor			Lave	Lave	UL	Lave	Lave	Uo,UL,TI
Power Consumption								
1) Energy used per unit area { = α / (2 x 3.65 x β) }		(W/m^2)	0.83	**0.60**	0.61	**0.50**	0.51	0.73
2) Energy efficiency (benchmark against HPS)		(%)	-66.00	-20.00	-22.00	0.00	-2.00	-46.00
3) Energy consumption per hour / km		(kWh)	12.15	8.73	8.96	7.33	7.50	10.71
4) Energy consumption per year / km		(kWh)	53,234	38,225	39,245	32,120	32,850	46,929

<u>Note:</u>

1) In the case where luminaire is measured using total flux method, the luminaire efficiency is given as 100% with the total lumen output of luminaire equal to the lamp luminous flux quoted above.

Table 2e. Comparison for ME2 lighting class – Single sided installation

Road Details							
1) Carriageway			Single carriageway				
2) Road width			4 x 3.65m (2 lanes per traffic direction)				
3) Median			-				
4) Road surface			R3 ; Qo = 0.07				
Installation Details							
1) Lighting system			LED			HPSV	
2) Luminaire type			USA	Europe-1	Europe-2	Malaysia	
3) Lamp power		(W)	204	-	215	250	400
4) System wattage (α)		(W)	237	257	228	285	450
5) Total luminous flux (lamp)		(klm)	15.6	29.9	23.4	33.2	56.5
6) Luminaire efficiency		(%)	100.0	82.3	71.2	81.2	83.6
7) Luminaire efficacy		(lm/W)	65.8	95.7	73.1	94.6	105.0
8) Lamp colour temperature		(K)	4000	4000	4250	2000	2000
9) Pole arrangement			Single sided			Single sided	
10) Mounting height		(m)	12	12	12	15	15
11) Pole spacing (β)		(m)	17	32	24	35	52
12) Setback of pole		(m)	1	1	1	1	1
13) Overhang		(m)	2	1	2	2	2
14) Arm length		(m)	3	2	3	3	3
15) Arm inclination			5°	5°	0°	10°	5°
16) Maintenance factor			0.717	0.717	0.717	0.8	0.8
Lighting Performance							
1) Lighting criteria	Required level						
a) Average luminance	Lave≥1.5cd/m^2		1.56	1.50	1.52	1.52	1.50
b) Overall uniformity	Uo ≥ 40%		45.4	44.0	42.5	44.1	43.1
c) Longitudinal uniformity	UL ≥ 70%		89.0	79.9	88.2	81.3	71.1
d) Threshold increment	TI ≤ 10%		5.7	9.8	9.6	9.2	9.3
e) Surround ratio	SR ≥ 0.5		0.5	0.5	0.5	0.5	0.6
2) Limitation factor			Lave	Lave	Lave	Lave	Lave
Power Consumption							
1) Energy used per unit area { = α / (4 x 3.65 x β) }		(W/m^2)	0.95	**0.55**	0.65	**0.56**	0.59
2) Energy efficiency (benchmark against HPS)		(%)	-69.64	1.79	-16.07	0.00	-5.36
3) Energy consumption per hour / km		(kWh)	13.94	8.03	9.50	8.14	8.65
4) Energy consumption per year / km		(kWh)	61,062	35,177	41,610	35,666	37,904

Note:
1) In the case where luminaire is measured using total flux method, the luminaire efficiency is given as 100% with the total lumen output of luminaire equal to the lamp luminous flux quoted above.

Finally, a comparison of retrofitting an existing lighting installation made in 1995 on a heavily used 3-lane dual carriageway highway in the Klang valley that uses 400W HPSV luminaires designed in the 1960s mounted on 12m mast and spaced 50m apart, to meet M1 lighting class of CIE 115-1995, following in the format of CIE 30.2. Table 3 shows the result of replacing the existing 400W luminaire with new generation of HPSV luminaire and the best LED luminaire determined in earlier comparisons.

Table 3. Comparison of retrofitting an existing installation

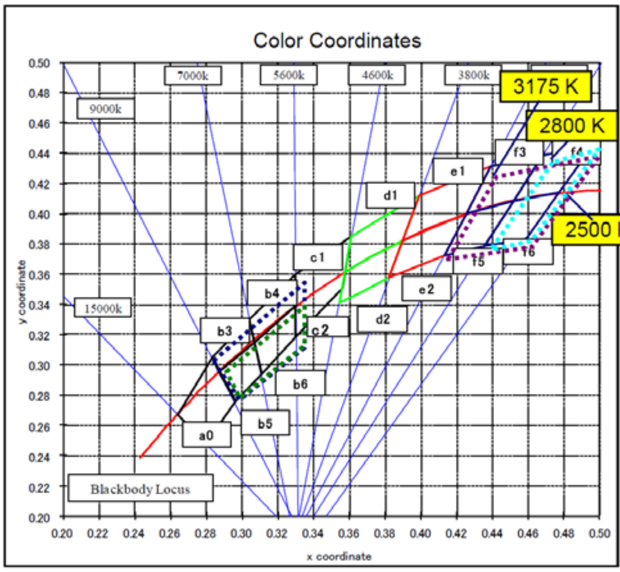
Road Details				
1) Carriageway			Dual carriageway	
2) Road width			3 x 3.65m / carriageway	
3) Median			0.5m	
4) Road surface			R3 ; Qo = 0.07	
Installation Details				
1) Lighting system			HPSV	LED
2) Luminaire type			Malaysia	Europe-1
3) Lamp power		(W)	250	-
4) System wattage		(W)	285	256.4
5) Total luminous flux (lamp)		(klm)	33.2	29.9
6) Luminaire efficiency		(%)	82.5	82.3
7) Luminaire efficacy		(lm/W)	96.1	96.0
8) Lamp colour temperature		(K)	2000	4000
9) Pole arrangement			Twin central	
10) Mounting height		(m)	12	12
11) Pole spacing		(m)	50	50
12) Setback of pole		(m)	0.25	0.25
13) Overhang		(m)	-0.25	-0.25
14) Arm length		(m)	0	0
15) Arm inclination			5°	5°
16) Maintenance factor			0.8	0.8
Lighting Performance				
1) Lighting criteria	Required level			
a) Average luminance	Lave ≥ 2cd/m^2		2.03	**1.58**
b) Overall uniformity	Uo ≥ 40%		41.2	46.6
c) Longitudinal uniformity	UL ≥ 70%		71.7	81.1
d) Threshold increment	TI ≤ 10% (15%)		9.8	8.3
e) Surround ratio	SR ≥ 0.5		0.5	0.6

4 Analysis of result

i) The luminaire efficacy for the 4 LED luminaire used in this study ranges from 65.8-96.7 lm/W instead of the 140-150 lm/W that we often heard. The reasons are:

a) LEDs are grown on a wafer substrate and then diced into tiny little LED chips. Unfortunately, every chip from the same wafer has different properties and hence need to be tested and sorted into bins according to colour, flux and forward voltage. Figure 2 shows an example of effect of bin and its price. Luminaire efficacy is therefore dependent on the combination of bins used in its manufacture. The lesser the number of bins used, the higher the performance and the higher the cost. The luminaire with the lowest luminaire efficacy could have used LEDs from more bins while that of higher efficacy uses LEDs from lesser number of bins.

Figure 2. Example of binning and price



Flux Bin	Min	Max
Rank P17	86 lm	102 lm
Rank P16	72 lm	86 lm
Rank P15	60 lm	72 lm
Rank P14	51 lm	60 lm

Color rank	Flux rank	Price
b5/b6	P14/**P15**/P16	100 %
b3/b4/b5/b6	P14/**P15**/P16	90 %
f3/f4/f5/f6	P15/**P16**/P17	100 %
f4/f6	P15/**P16**/P17	116 %
f4/f6	**P16**/P17	130 %

b) The other factor affecting the luminaire efficacy is the driver efficiency as the luminaire system efficacy is a product of lamp/LED efficacy and driver efficiency.

c) Optical efficiency and thermal efficiency, which are usually reflected in the luminaire efficiency, have a direct impact on the LED luminaire system efficacy. Luminaire with good thermal management and better optics generally give a better efficiency.

ii) The luminaire efficacy (row 7 under the ‘Installation Details’ of Table 2) for different luminaire layout is different. The highest luminaire efficacy does not necessarily result in the most energy efficient solution. For example, the luminaire efficacy of the most energy efficient solution for opposite installation for LED, ME1 lighting class, is 96.5lm/W while that for ME2 lighting class is 93.1lm/W. Similarly, for HPSV system, ME2 lighting class, opposite staggered layout, the photometry with 150W giving luminaire efficacy of only 81.5lm/W is 2% more efficient than the photometry using a 250W lamp giving a luminaire efficacy that is 16% more at 94.4lm/W.

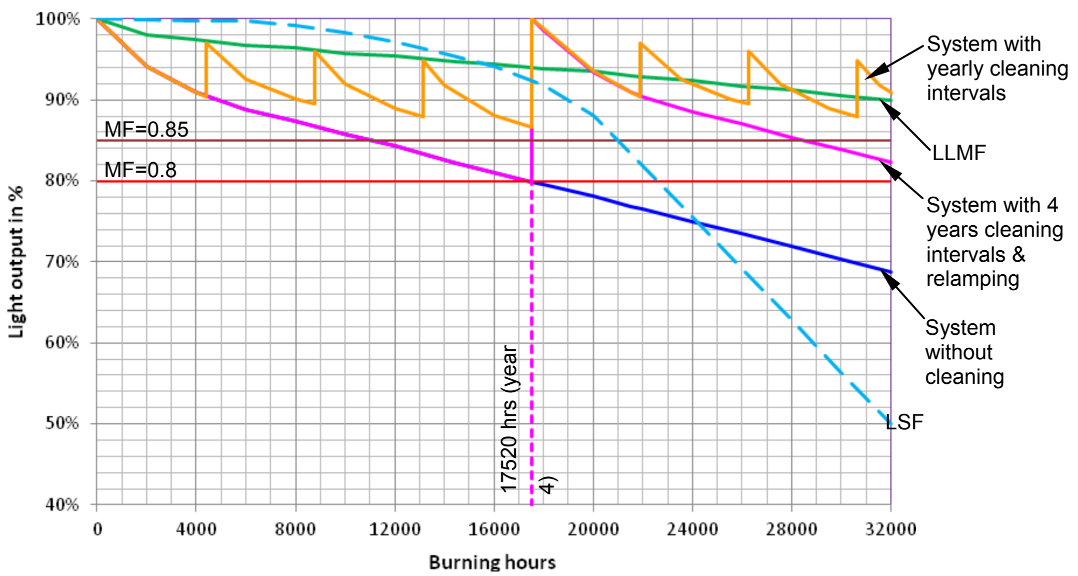
Comparing the Europe 1 and 2 LED luminaire for twin central, ME1 lighting class, the difference in luminaire efficacy is 31% but the energy used per square meter is only 16%. For opposite installation, ME1 lighting class, the difference is 32% and 12% respectively. Herein, the photometry of Europe 2 LED luminaire is much better than that of Europe 1 for these two applications. From the above observation, the photometry or light utilisation of the luminaire also has a big influence on the energy usage in road lighting. It is therefore, erroneous to conclude that high lamp efficacy or luminaire efficacy alone will result in a more energy efficient road lighting.

iii) For 3-lane dual carriageway where luminaire lay-out is limited to either central median or opposite installation, the HPSV luminaire is more energy efficient by 8% for opposite installation and 15% for central median installation as compared to the best LED luminaire available after August 2011 in Europe.

iv) For the 4-lane carriageway, the most energy efficient lay-out for LED luminaire can either be single sided using a luminaire with luminaire efficacy of 95.7lm/W (Table 2e) or opposite using a luminaire with luminaire efficacy of 93.1lm/W (Table 2c), where energy used is 0.55 watt per meter square. The best for HPSV is opposite staggered using 0.5 watt per meter square (Table 2d), which is 10 % better than that achieved by best LED luminaire.

v) As the MF of LED is 0.717, the initial lighting level will be nearly 40% higher than the required level, or 2.8cd/m^2 for LED system compared to 2.5cd/m^2 for HPSV for ME1 lighting class. Energy utilisation can be improved by increasing the MF and this is possible by cleaning the luminaire yearly because the luminaire depreciation is 8% in the first year. Figure 3 shows the system light output as a function of lighting hours for one year and four year cleaning cycle for HPSV luminaire. With one year cleaning cycle, the MF can be increased to 0.85 resulting in another saving of 6.25% energy. On the other hand, MF of 0.717 seems to be the optimum for LED luminaire. From Figure 4, for MF of 0.8, the system output of LED luminaire will be insufficient to meet the specified lighting level by 28,000 lighting hours even after cleaning. The economic lifespan of LED luminaire will be reduced to about 20,000 hours or about 4.5 years if MF is change to 0.8. In this case LED lifespan is not much better than HPSV and the cost of maintenance will be much higher given the current cost of LED, LED module and LED luminaire. From here, it can be observed that the often quoted long lifespan of LED is irrelevant without considering how it is used.

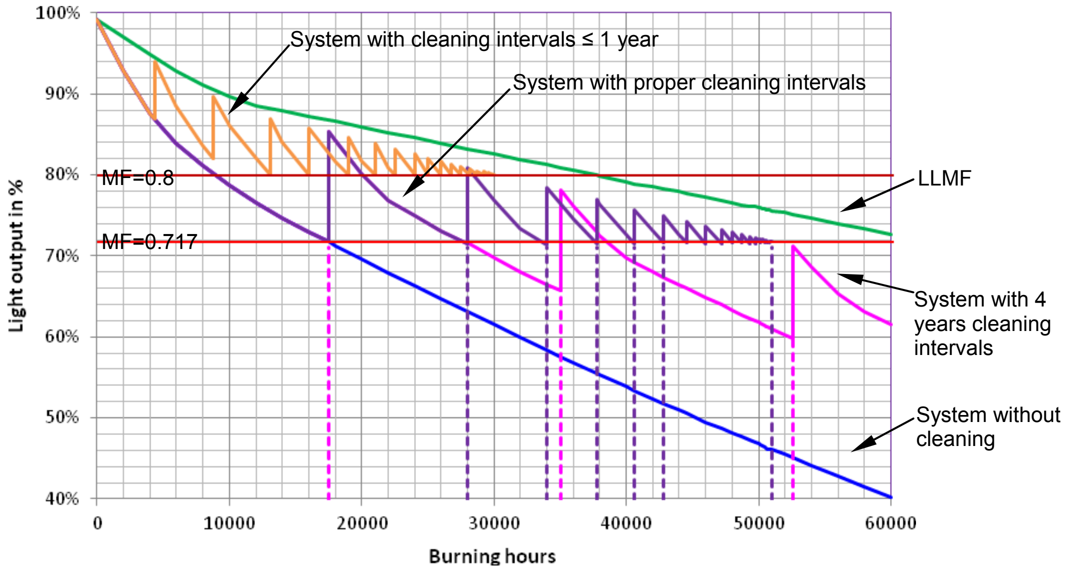
Figure 3. Light output as a function of lighting hours – HPSV luminaire



Conditions:		Assumption:
- ambient temperature	: 28°C	- assuming no degradation for the glass protector
- pollution	: medium	- burning hours = 4380 hours per year (i.e. 12hrs/night)

vi) From Figure 4, in order to ensure that the safe lighting level is maintained the cleaning interval for LED luminaire shortens progressively with operating hours thus presenting additional challenges in maintenance and budget planning.

Figure 4. Light output as a function of lighting hours – LED luminaire



Conditions:			Assumption:
- driving current	:	350mA	- assuming no degradation for the glass protector
- ambient temperature	:	28°C	- burning hours = 4380 hours per year (i.e. 12hrs/night)
- pollution	:	medium	
- optical lens	:	PMMA	

vii) It is very important to note that the MF presented in this study is for LED operated at 350mA with PMMA lens and glass cover. From Appendix C, the MF will be lower if LED is operated at more than 350mA, made worst with lens made of Polycarbonate material and Polycarbonate cover.

viii) Table 3 shows old 400W HPSV luminaire can be replaced with new generation of 250W HPSV luminaire on a one to one basis thus saving 40% energy directly. It is not possible to do the same with the best LED luminaire available now and with MF of 0.8 as the maintained lighting level is only 1.58cd/m^2. This comparison again reinforce that it is inaccurate to compare luminaire for luminaire without considering the way the luminaire is to be used.

5 Initial cost for best energy efficient solution

For ME1 lighting class, the best energy efficient solution for LED luminaire is the same for both twin central and opposite layout using 0.69 W/m^2 while that for HPSV is twin central layout using 0.60 W/m^2. Hence, initial cost is calculated for twin central layout (Table 4).

For ME2 lighting class, the best energy option for LED luminaire is for opposite or single-sided layout using 0.55 W/m^2 energy while that for HPSV is for opposite staggered using 0.5 W/m^2. The initial cost calculation for ME2 lighting class is based on the more cost efficient and therefore less environmental impact, single-sided installation for LED luminaire and staggered for HPSV luminaire (Table 4).

Since the costs of design, transformer stations, feeder pillars, cables etc. are practically equal in both cases, only poles, brackets, luminaires and lamps and their installation were compared (Kostic, Djokic, Pojatar, 2009).

Table 4. Initial cost comparison

		ME1 Lighting Class		ME2 Lighting Class	
		LED	HPSV (400W)	LED	HPSV (150W)
a) Pole height	(m)	12	15	12	12
b) Spacing	(m)	34	69	32	48
c) Pole arrangement		Twin central	Twin central	Single-sided	Opposite staggered
d) No. of pole / km		30	15	31	42
e) No. of luminaire / km		60	30	31	42
f) Cost of pole + installation	(RM)	1500	3000	1500	1500
g) Cost of luminaire + installation	(RM)	6000	1300	6000	1200
Total Initial Cost	(RM)	405,000	84,000	232,500	113,400

For an <u>energy optimised</u> lighting solution, the LED system cost roughly RM320,000.00 per km more for ME1 lighting class and RM120,000.00 more per km for ME2 lighting class.

6 Lifespan and Maintenance cost comparison of HPSV and LED luminaire

For road lighting, the lifespan of lamp is when the system light output cannot be economically maintained to ensure that the specified lighting class is met. As demonstrated in Figure 3 and 4, the lifespan is also dependent on the MF used under the circumstances. In the case of LED luminaire, if MF of 0.717 is used, the economical lifespan can be stretched to about 42,000 hours but with 5 cleaning scheduled as shown in Figure 4. If energy efficiency takes priority, then a higher MF of 0.8 may be used, but the economical lifespan is shortened to about 20,000 lighting hours or 4.5 years. If MF of 0.8 is used, then the lifespan of LED luminaire is not any better than HPS lamp. And then the whole luminaire will have to be changed. This demonstrate that the often quoted and emphasized long lifespan of LED is meaningless or irrelevant without considering under what circumstances it is used. In the case of HPSV luminaire, only the lamp has to be changed and luminaire cleaned every 4 years if we used a MF of 0.8. During this period, an 8% lamp outage may be expected. The luminaire life span of 20 years can be expected. (Luminaires installed on the Penang Bridge were changed after more than 22 years with some are still in use). Table 5 shows the cost comparison for a 20 year period for the most energy efficient LED luminaire with HPSV luminaire. To make it simple, current rates are used.

Table 5. Maintenance cost per kilometer over 20 years (most energy efficient)

Descriptions	3-lane dual carriageway		4-lane single carriageway	
	LED	HPSV	LED (single sided)	HPSV (staggered)
No. of luminaire / km	58	30	31	42
No. of cleaning over 20 years	10	4	10	4
Total cleaning cost over 20 years (RM50 each)	**29,000**	**6,000**	**15,500**	**8,400**
Relamping over 20 years (times)	-	4	-	4
Cost of relamping (RM / each)	-	200	-	200
Total relamping cost over 20 years	-	**24,000**	-	**33,600**
Unscheduled relamping (8%)	-	2.4	-	3.36
Total unscheduled relamping over 20 years	-	12	-	16.8
Unscheduled relamping cost (RM / each)	-	400	-	400
Total unscheduled relamping cost over 20 years	-	**4,800**	-	**6,720**
Luminaire change over 20 years	58	-	31	-
Cost of luminaire	7000	-	7000	-
Labour to change	300	-	300	-
Total luminaire cost	**423,400**	-	**226,300**	-
Driver maintenance over 20 years (17.5%, assuming 0.2% failure per 1000 hours when operated at component t_c)	10.16	5.26	5.43	7.36
Cost of driver / control gear (RM / each)	700	100	700	100
Labour to change	300	300	300	300
Total driver maintenance cost	**10,160**	**2,104**	**5,430**	**2,944**
Maintenance cost over 20 years	**462,560**	**36,904**	**247,230**	**51,664**

Note: At the time of preparing this report, there is no standardisation of LED or LED module whereby the LED or LED module can be replaced irrespective of make or brand of luminaire. LED chip development is also transforming rapidly and it is unlikely that the LEDs or LED modules made 10 years in the future can be used to replace LED module used in today's LED luminaire.

The total maintenance cost per kilometer over 20 years of LED is **more than 12.5 times** that of HPSV for 3-lane dual carriageway and about **5 times** for 4-lane single carriageway. Even if LED luminaire were to cost half in ten years' time (possible??) the maintenance cost is still nearly 6.5 times and 2.5 times that of HPSV.

7 Environmental impact

A very detailed environmental impact assessment titled "Preparatory Studies for Eco-design Requirements of EuPs" was carried out by the European Union and the Final Report completed in January 2007. Detail assessment on the energy using products (EuPs) for road lighting was carried out for the production phase, distribution phase, use phase and end of life (disposal) phase and conclude that focus should be on energy efficiency in order to reduce environmental impact (Chapter 4 and 5 of Final Report). (The Final Report has 344 pages and can be downloaded at http://www.eup4light.net/assets/pdffiles/Final/VITOEuPStreetLightingFinal.pdf). However, this study covers luminaire using High Intensity Discharge (HID) lamps whereby a lifespan of 30 years has been well established.

It is also well established that more resources used will cause more environmental impact and will be reflected in the cost of the product, installation, operation, maintenance and finally disposal.

In the case of road lighting, we have established that comparisons should be based on per unit length of road to be lit to the required lighting class. Our assessment here will accordingly be based on a per km basis, whereby the initial cost covers resources used to produce, distribute and install the luminaire, the use phase covers the energy used per km, the maintenance cost covers the maintenance per km over 20 years and the disposal cost for the disposal phase of the luminaire.

Generally, 5% of material used in the production of a luminaire goes to the landfill at the end of life, 90% of plastics incinerated, 9% recycled, 95% of metal and glass recycled, 90% of Hg captured in processing of waste lamp [EuP Final Report].

Looking at the current construction of LED and HPSV luminaire, and in the absence of detailed data, we assume that environmental impact for both type of luminaire complete with gear and lamp is the same, or difference is negligible during disposal. Therefore, the environmental impact will be the direct ratio of the number of luminaire to be disposed. As demonstrated earlier, the lifespan of current generation LED luminaire is about half that of HPSV luminaire. Table 6 shows environmental impact of LED and HPSV system for the best energy efficient solution for the current Best Available Technology (BAT) LED and HPSV lighting system.

Table 6. Environmental impact of LED and HPSV system

		ME1 Lighting Class		ME2 Lighting Class	
Description		LED	HPSV (400W)	LED	HPSV (150W)
Production, distribution & installation phase					
a) Total initial cost	(RM)	405,000	84,000	232,500	113,400
b) Environmental impact ratio during production, distribution & installation phase (benchmark against HPS)		**4.82**	**1**	**2.05**	**1**
Use phase (operation & maintenance)					
a) Energy consumption per year / km	(kWh)	65,958	57,130	35,177	32,120
Environmental impact ratio (benchmark against HPS)		1.15	1	1.10	1
b) Maintenance cost over 20 years	(RM)	462,560	36,904	247,230	51,664
Environmental impact ratio (benchmark against HPS)		12.53	1	4.79	1
c) Environmental impact ratio during use phase (benchmark against HPS)		**6.84**	**1**	**2.95**	**1**
Disposal phase					
a) No. of luminaire / km	(nos.)	60	30	31	42
b) No. of luminaire to be disposed over 20 years	(nos.)	120	30	62	42
c) Environmental impact ratio during disposal phase (benchmark against HPS)		**4**	**1**	**1.48**	**1**
Total environmental impact ratio (benchmark against HPS)		**5.22**	**1**	**2.16**	**1**

Total environmental impact of LED system is more than 5 times that of HPSV for ME1 lighting class (3-lane dual carriageway) and more than 2 times for ME2 lighting class (4-lane single carriageway).

8 Recommendations

i) The maintenance factor used in this exercise is based on a 4 year cleaning cycle. The energy usage can be reduced by about 9% if cleaning is done every year. We therefore recommend that the Government make it a national policy to clean the road luminaire every year so that road lighting design will in future be based on yearly cleaning interval.

ii) The light depreciation rate of LED is currently derived using the IESNA TM21 lumen maintenance model and there is no validated model to predict or derive the lumen depreciation rate of LED package used in a module where there are many other complex influencing parameters. For example, it is widely recognized that the LED characteristics are strongly temperature dependent. The same LED when used in different luminaire with different thermal management could have different lifespan and lumen maintenance. The maintenance factor (MF) derived in this study is at most a good estimate. If it is on the conservative side, the economic impact and environmental impact could have been lower as the lighting level will be above the safe level for a longer period of time. However, there remains the risk that it is too optimistic thus risking the possibility that the safe lighting level could not be maintained. The economic and environmental impact in this scenario will thus be higher. Hence, it is recommended that the LED luminaire be tested for the light depreciation rate instead of a vague estimation based on the data of LED package.

iii) It is <u>erroneous</u> to conclude that high lamp efficacy or luminaire efficacy alone will result in a more energy efficient road lighting as the photometry or light utilisation of the luminaire (which is also dependent on the geometrical layout) and the maintenance practice (which in turn depends on the luminaire specification and the pollution category) have also a big influence on the energy usage in road lighting. As energy usage is of prime concern, we recommend that the energy used per square meter of road surface to be lit to a specified lighting class be the main specification and bidders are allowed to offer an energy efficient and lowest life cycle cost lighting solution rather than the current practice of specifying the type of lighting system, lamp power and pole height resulting in uncertain lighting quality and poor energy efficiency.

iv) Zhaga consortium is developing standard specifications for the interfaces of LED light engines to enable interchangeability between products made by diverse manufacturers. As this consortium is an industry wide cooperation, their standard specifications will eventually be the industry standard and become international. As such, we recommend the LED luminaire are made to comply with Zhaga standard specifications for use in an ambient temperature of 35 degree centigrade or more and humidity of not less than 90%.

v) With the inclusion of MF in the design of road lighting, the initial lighting level will be higher by the factor of 1/MF. Energy can further be saved by varying the power to the lamp to compensate for the MF during the life of the lamp thus providing a Constant Light Output (CLO) to the lit area. A saving of up to 25% for HPSV is possible with the additional benefit in increasing lamp life of up to 100%. CLO can also be applied to LED. We therefore recommend that CLO to be considered if the benefit outweighs its total life cycle cost.

vi) The specified lighting class is to provide safe lighting level for peak traffic condition which is generally at the early part of the night and about an hour before dawn. During period of low traffic, the lighting level can be dimmed to the appropriate level thus saving up to 20% energy use per night. Hence, dimming should be considered if the savings is substantially more than the life cycle cost of the dimming equipments.

vii) LEDs of higher colour temperature generally give a higher efficacy as compared to LEDs of lower colour temperature. Nonetheless, using LEDs of higher colour temperature in road lighting may incur potential hazard to road users especially during mist or rainy conditions as the contrast of the view may be reduced if LEDs of higher colour temperature (whiter) are used. Hence, we recommend that only LEDs with colour temperature lower than 3500K be used in road lighting for the time being while research is carried out to study this potential safety hazard.

9 Conclusion

LED innovation and development continue to move forward in a furious pace and can now be offered as a viable alternative lighting solution in many areas of lighting. However, for road lighting, even with the latest Best Available Technology LED luminaire, there is no advantage over the most energy efficient solution using the most efficient HPSV system at this moment. The conclusion is summarised in the following table.

	Advantage of using LED	For 3-lane dual carriageway (ME1 lighting class)	For 4-lane bi-directional carriageway (ME2 lighting class)
1) Energy saving	No	LED use 15% more power	LED use 10% more power
2) Cost saving	No	Increase initial cost by 5 times with LED products	Increase initial cost by 2 times with LED products
3) Maintenance cost over 20 years	No	12.5 times more with LED products	5 times more with LED products
4) Safety and security	No	Impact of LED on road lighting is still under deliberation. Current lighting standards have to be respected, or public safety will be compromised.	
5) Environmental impact	No	5 times more using LED products	2 times more using LED products

The economic and environmental impact of LED luminaire for road lighting may be substantially reduced when interchangeability of LED light engine between different manufacturers through industry wide product standard specification, currently undertaken by Zhaga consortium, is finalised and implemented. Coupled with more mature level of innovation and development, LED will become a viable alternative lighting solution for road lighting in the near future.

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