Comparison of Road Lighting Luminaires for M2 Road Lighting Class Considering Energy Efficiency

[Ramazan Ayaz, Asiye Kaymaz, Hakan Akca, Ali Ajder, Adem Unal, Mugdesem Tanrioven]

Abstract— **Using LED luminaires instead of luminaires with conventional lamps may lead better energy savings and energy efficiency. In order to decide to choose more efficient road lighting system a comparison between conventional lighting luminaires and LED based luminaires should be examined. In this study, the luminaires with high pressure sodium (HPS) lamp which is the most widely used technologies in road lighting and less frequently used luminaires with metal halide (MH) lamps analyzed and compared with LED luminaires. The photometric data of the three different luminaries were investigated by using Goniophotometer and Integrating Sphere in the laboratory. After that, the obtained data applied to a sample road model in Dialux software program. Lighting designs using different types of lighting luminaires are created by taking minimum criteria of CIE standards for M2 lighting class into consideration. This study shows that 36.6% energy saving can be achieved in case of using new LED technology instead of the currently used HPS technology. Also payback period is estimated as 13 years with energy prices of Turkey. In case of using luminaires with MH lamps are going to be 51.1% energy saving and 9.3 years payback period respectively.**

Keywords— **Road lighting, energy efficiency, LED luminaire, M2 road class**

I. INTRODUCTION

Nowadays, fossil fuels are consumed rapidly, CO_2 emissions and global warming are also increasing due to increase of energy consumption. Therefore, studies and applications related to energy saving and energy efficiency have become more important day by day. New generation products in parallel with the developing technology are created in lighting and the current lighting systems have been improved.

The energy consumption for lighting is about %20 of the total consumed electrical energy in the world. Also about 3% of this ratio is used by road lighting [1]. This rate may seem like low. The amount of energy consumption annually in Turkey is nearly 245 billion kWh so energy saving will be provided significantly thanks to make improvement in the part of %3 [2].

Traffic load has increased with advancing technology and energy consumption in the developing society. Traffic flow is not only heavy in daytime but also it increasingly continues in the night-time when we can't take advantage of daylight [3]. In addition, night-time accidents occur more in number and more severe than daytime accidents [4][5]. Most part of these accidents happens due to vision problems [6]. Therefore, optimum road lighting is needed for the lessening of traffic accidents, driver's comfort and driving safety. Besides reduction of electric consumption and maintenance expenditures for optimum road lighting, average luminance (L_{ave}), overall luminance uniformity (U_0), longitudinal luminance uniformity (U_l), threshold increment (TI) and surround ratio (SR) are important parameters in road lighting design [7][8][9].

HPS, MH and LED luminaires are generally used in road lighting. High luminous efficacy, long life and proven reliability are the main characteristics of the most widely used HPS lamps in road lighting [1][10][11]. MH lamps are also preferred particularly in urban roads where visual quality is at the forefront owing to their high color rendering and high color temperature features. In the recent years, high luminous efficacy values are provided by means of rapid developments in LED technology. CREE Company reached 254 lm/W luminous efficacy in the laboratory conditions[13].

In this manuscript; HPS, MH and LED luminaires were analyzed by comparison on a sample road model in the Dialux Software program. This manuscript was organized as follows: sample road model, Case 1 and Case 2 are presented in Section II. The calculated energy costs and payback time of luminaires are given in Section III. Eventually, conclusions are discussed in Section IV.

II. EXPERIMENTAL STUDY

In this study, photometric measurements of road lighting luminaires are acquired by using far field Goniophotometer and Ulbricht Sphere in the laboratory. The C plane of goniophotometer is the most suitable method to measure luminous intensity distribution of lighting luminaire. The representation of luminaires in the (C,γ) coordinates system and goniophotometer measurement setup are given in Fig. 1 and 2 respectively.

Ramazan Ayaz/Asiye Kaymaz/Hakan Akca/Ali Ajder/
Adem Unal/Mugdesem Tanrioven

Yildiz Technical University
Turkey

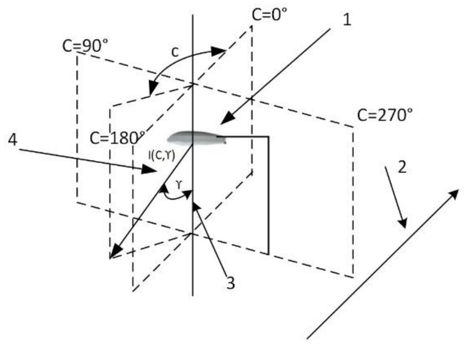

Fig. 1 The representation of luminaires in the (C, γ) coordinate system.

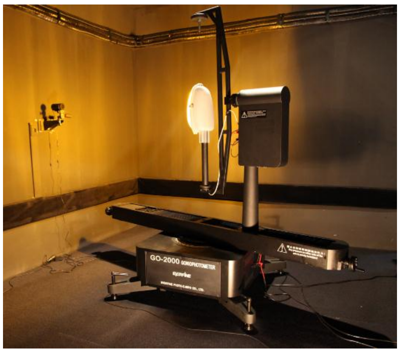

Fig. 2 Goniophotometer measurement setup

After total luminous flux of light sources was measured with Ulbricht Sphere, the luminaires are measured according to EN13201-3 standard (calculations of performance road lighting) by using Goniophotometer device [14]**.** As the results of measurements are obtained the maximum luminous value, the coordination of the maximum luminous intensity I(C,γ), the luminous intensity distribution curve, luminous efficacy and the total luminous flux.

The four different luminaires are used in this study. Two of them were HPS and MH luminaires with 150W conventional light sources and the others are 80W and 150W LED luminaires having the same design. Photometric and electrical values of these luminaires are given in Table 1.

TABLE 1. PHOTOMETRIC AND ELECTRICAL VALUES OF FOUR DIFFERENT LUMINAIRES

Luminaire Name	Luminaire Power (W)	Power Factor	Luminous Flux (lm)	Luminous Efficacy (lm/W)	Max. Luminous Intensity (cd/klm)	Imax θ (C,γ)
150W HPS Luminaire	166*	0.9392	13087.44	78.84	370.3	5;24
150W MH Luminaire	163.5*	0.9392	9554.94	58.44	481.4	180;58
105W LED Luminaire	105	0.9641	11756.85	111.97	560.2	135;50
80W LED Luminaire	80	0.9337	8664.8	108.31	395.5	45;49

**It is included ballast losses.*

Luminous intensity values of these luminaries are attained with 5º intervals between 0-355º at the 72 different C planes and γ angles were measured with 1º intervals between 0-90º for each C plane. The luminous intensity values are given as cd/klm unit. The light distribution curve of each luminaire is shown in Fig. 3.

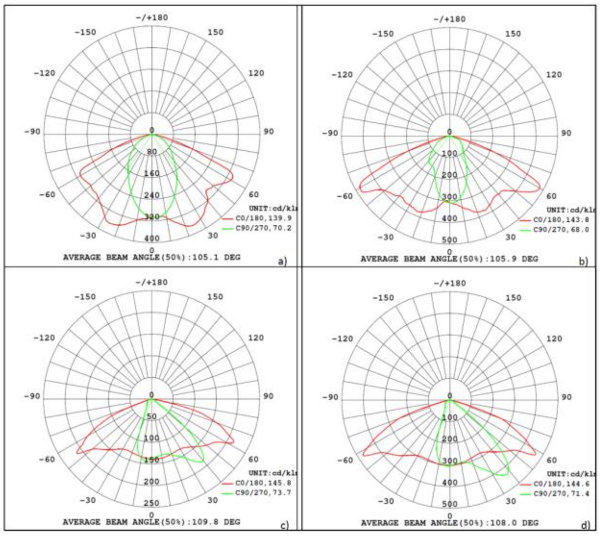

Fig. 3 Luminous intensity distribution curves of the luminaires in the C plane a) 150W HPS b) 150W MH c) 90W LED d) 105W LED.

A. *Dialux Roadway Model*

The proposed road model belongs to the M2 road class which allows middle and high driving speed designed for motorized vehicle traffic [15]. The road model consists of four-lane divided road. The width of each lane is 3.5m. The road model is illuminated with the opposite arrangement at A1 lighting situation. Road surface has been considered as R3 pavement class.

Luminaire maintenance factor is considered to be 0.89 because luminaire protection factor is IP66 [16]. The designed road model is given in Fig 4.

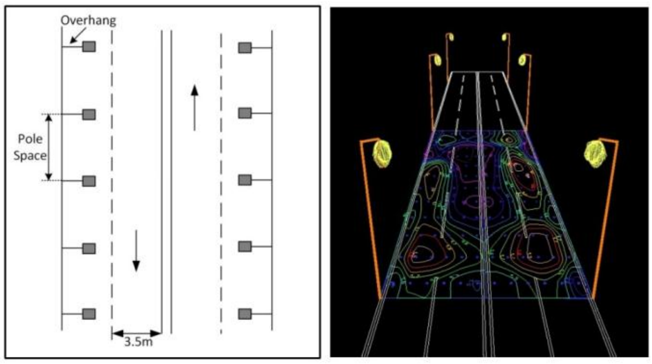

Fig 4. Designed road model

B. *Case 1: A Comparison Between 150W HPS and 105W LED Luminaires*

The photometric measurement results of each luminaire obtained from Goniophotometer are saved in ELUMDAT format. It is analyzed replacing the conventional HPS luminaires by the new generation LED luminaires. In the first stage, data of 150W HPS luminaire are integrated into the road model. Mounting height (h), overhang (oh) and luminaire arm angle (θ) are determined that achieve the minimum road lighting criteria for providing the maximum pole space (s). In the second stage, 105W LED luminaire is integrated into the road model without changing pole space. As a result, using LED luminaires is succeeded for min. road lighting criteria. Lighting arrangement values and road lighting parameters for case 1 are given Table 2.

TABLE 2. LIGHTING ARRANGEMENT VALUES AND ROAD LIGHTING CRITERIA FOR CASE 1

	Lighting Arrangement Values				Road Lighting Criteria				
Type of Luminaire	**s (m)**	**mh (m)**	**oh (m)**	**θ (º)**	**L_{av} ≥1.50**	**U_o ≥0.40**	**U_l ≥0.70**	**TI (%) ≤10**	**SR ≥0.50**
150W HPS Luminaire	35	11	1	10	1.57	0.77	0.76	5	0.84
105W LED Luminaire	35	11	1	5	1.52	0.81	0.75	6	0.82

As is also understood from Table 2, the arm angle of LED luminaire was only changed as 5º without changing road arrangement. When the distance of poles was optimized, it was seen that both luminaires provided minimum road lighting criteria at maximum 35m pole space. Acquired uniform luminous distributions of HPS and LED luminaires in the road surface are seen in the contour lines which are given in Fig. 5 and 6. The light distribution curves in the road surface is given by the observer close to the pole position for both the carriageways. Observer coordinates for first carriageway are -60m, 1.75m, 1.5m. Here, the distance between observer and pole is 60m. The width of observer position from the edge of the lane is 1.75m and the height of the observation point is 1.5m. For the second carriageway, distances are -60m, 12.25m, 1.5m respectively.

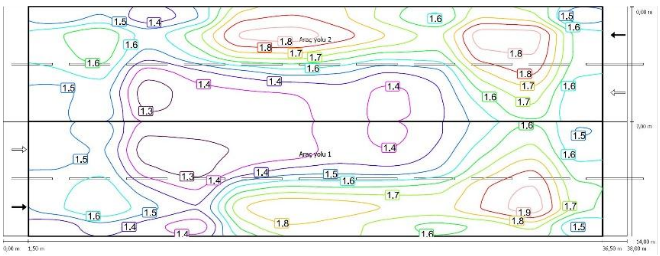

Fig 5. Contour lines in the road surface for 150W HPS luminaire

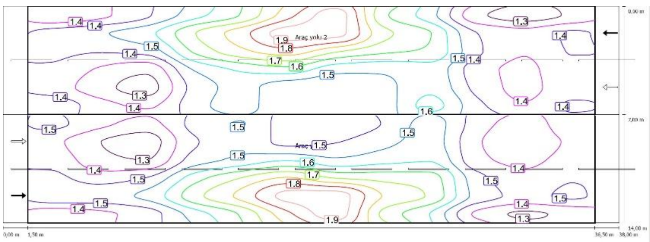

Fig 6. Contour lines in the road surface for 150W HPS luminaire

C. *Case 2: A Comparison Between 150W MH and 80W LED Luminaires*

As in Case 1, 150W MH luminaire is integrated to the sample road model. Maximum pole space was determined to provide the minimum criteria of road lighting. In this condition, on max. pole space, 80W LED luminaires are replaced by MH luminaires and it is seen that LED luminaires supplied required road lighting criteria. The measurement results for case 2 are given in Table 3.

TABLE 3. LIGHTING ARRANGEMENT VALUES AND ROAD LIGHTING CRITERIA FOR CASE 2

	Lighting Arrangement Values				Road Lighting Criteria				
Type of Luminaire	**s (m)**	**mh (m)**	**oh (m)**	**θ (º)**	**L_{ave} ≥1.50**	**U_0 ≥0.40**	**U_l ≥0.70**	**TI (%) ≤10**	**SR ≥0.50**
150W MH Luminaire	27	10	1	5	1.57	0.57	0.77	6	0.77
80W LED Luminaire	27	10	1	5	1.50	0.80	0.86	5	0.83

As seen in Table 3, the same lighting arrangement is used for both luminaires. When the distance of poles was optimized, it was found that each luminaire provided minimum road lighting criteria at maximum 27m pole space. Attained uniform luminous distributions of MH and LED luminaires in the road surface are seen in the contour lines which are shown in Fig. 7 and 8. The observer coordinates are same for both carriageway as is given in Case 1.

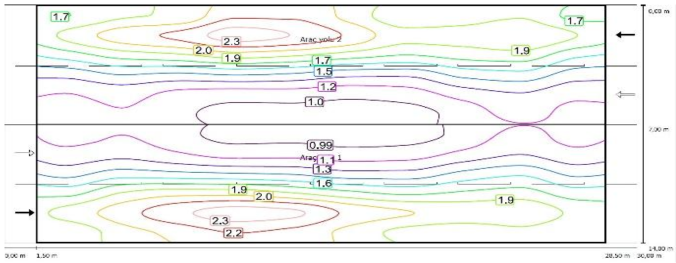

Fig 7. Contour lines in the road surface for 150W MH luminaire

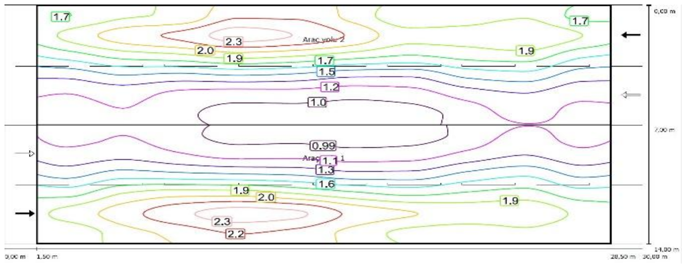

Fig 8. Contour lines in the road surface for 80W LED luminaire

III. ENERGY COSTS AND RESULTS

Total energy consumption per kilometer of luminaires is calculated in cases 1 and 2. In case of using LED luminaires instead of conventional luminaries, energy saving rate is calculated considering equation 1.

$$\% = \frac{W_C - W_{LED}}{W_C} X100 \qquad (1)$$

Where, W_C and W_{LED} is energy consumption of conventional luminaires and LED luminaires respectively. The calculated power values, number of pole and energy saving rate for case 1 and 2 are given in Table 4.

TABLE 4. CONSUMED POWER, NUMBER OF POLE AND ENERGY SAVING RATE PER KM

	Type of Luminaire	Number of Pole/km	Consumed Power (W/km)	Energy Saving/km (%)
Case 1	150W HPS Luminaire	58	9628.0	36.6
	105W LED Luminaire	58	6107.4	
Case 2	150W MH Luminaire	74	12099.0	51.1
	80W LED Luminaire	74	5912.6	

As it is seen in Table 4, 36.6% energy saving was provided when replacing the current 150W HPS luminaires with 105W LED luminaires in M2 road lighting class. Likewise, 51.1% less energy consumption has occurred when using 80W LED luminaires instead of 150W MH luminaires.

The payback time in term of energy saving for both cases is calculated equation 2 below. LED luminaire cost and unit electrical energy cost were taken into account in calculation of payback time.

$$\text{Payback Time (year/km)} = \frac{\text{LED Luminaire (\$/km)}}{\text{Energy Saving (\$/year.km)}} \quad (2)$$

In this study, costs of the 105W LED and 80W luminaires are 200 $/piece and 190 $/piece respectively. Daily operation time of luminaires is assumed to be 10 hours and total annual operating time is 3650 hours. Unit electrical energy cost for lighting is 0.067$ per kWh in Turkey [17]. Annual energy cost savings per km is calculated using following equation.

$$\text{Annual Energy Cost Savings (\$/year)} = \text{Power Saving (kW/km)} \text{ xAnnual Operation Time (h)xUnit Energy Cost (\$/kWh)} \quad (3)$$

Calculated total costs and payback times are given in Table 5 for cases 1 and 2.

TABLE 5. COST ANALYSIS OF CASE 1 AND 2

	LED Price ($/piece)	Number of LEDs (no/km)	LED Total Cost ($/km)	Energy Unit Cost ($)	Energy Power Saving (kW/km)	Energy Saving Cost ($/km.year)	Payback Time (year)
Case 1	200.00	58	11600.00	0.067174	3.5206	863.199	13.4
Case 2	190.00	74	14060.00	0.067174	6.1864	1516.813	9.3

As shown in Table 5, annual energy cost savings per km for both cases are determined to be 863.199 $ and 1516.813 $, respectively. According to provided energy saving for the two cases, payback time is found to be 13.4 and 9.3, respectively.

MH luminaires provide road lighting criteria with short pole space in comparison with HPS luminaires. Thus, energy consumption and the number of using MH luminaires are more than HPS luminaires. The same road lighting criteria can be provided with using low power LED luminaire at the same pole space. As a result, payback time diminishes for LED luminaires.

IV. CONCLUSION

In this study, photometric values of different types of road lighting luminaires which belong to M2 road class are measured in the laboratory and light distribution curves are obtained. These data are used in M2 road model which is created in Dialux software program.

In the first case, 150W HPS luminaires are placed on the sample road model with opposite lighting arrangement. Maximum pole space which provides the minimum road lighting criteria is determined. Then, the simulation is repeated with 105W LED luminaires. The simulation results showed that the energy saving is achieved 36.6% and the payback time is 13.4 years for LED luminaires.

In the second case, 150W MH are placed to sample road model. Maximum pole space is specified for minimum road lighting criteria in the same way. However, 80W LED luminaires that allows these requirements in the same lighting conditions have been replaced with MH luminaires. The results of the analysis showed that 51.1% of the energy savings is achieved and the payback time was 9.3 years for LED luminaires.

Consequently, using LED luminaires instead of conventional luminaires is significantly contributed to energy saving in M2 road class. According to calculated results, payback time of LED luminaires is too long for lifetime of LEDs. However, LED luminaire cost has gradually fallen in price based on developing LED marketing and it is expected to decrease this time. Moreover, payback time is got shorter in some countries where energy unit cost is higher because of increasing energy saving cost. Nowadays, rapidly consumption fossil fuels, increasing CO_2 emissions and global warming has shown that how important energy saving and energy efficacy are.

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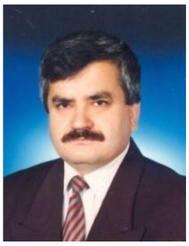
About Author (s):

Ramazan Ayaz received the M.Sc. degree in the Department of Electrical Engineering from Yildiz Technical University in 2012, Turkey. He is currently pursuing doctoral study. He is working as a Research Assistant in the Department of Electrical Engineering, Yildiz Technical University.

Asiye Kaymaz received the B.S. degree in Electrical Engineering and Mechanical Engineering from Yildiz Technical University 2014, Turkey. She is currently pursuing master study in Yildiz Technical University.

Hakan Akca received the M.Sc. degree in the Department of Electrical Engineering from Yildiz Technical University in 2011, Turkey. He is currently pursuing doctoral study. He is working as a Research Assistant in the Department of Electrical Engineering, Yildiz Technical University.

Ali AJDER received the M.Sc. degree in the Department of Electrical Engineering from Yildiz Technical University in 2011, Turkey. He is currently pursuing doctoral study. He is working as a Research Assistant in the Department of Electrical Engineering, Yildiz Technical University.



Adem Ünal received the PhD. degree in Electrical Engineering from Yildiz Technical University in Turkey. Now, he is Assistant Professor in Electrical Engineering in Yıldız Technical University. His research areas lighting technologies and circuit theory.

Mugdesem Tanrioven received the PhD. degree in Electrical Engineering from Yildiz Technical University in 2000, Turkey. Now, he is Head of Department of Electrical Engineering in Yıldız Technical University, Turkey. His research areas include renewable energy, power system reliability.