Light & Engineering
Vol. 27, No. 1, pp. 61–70, 2019

LIFE CYCLE COST ANALYSIS ON M1 AND M2 ROAD CLASS LUMINAIRES INSTALLED IN TURKEY

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ABSTRACT

This paper investigates and compares the photometric performance and lifetime cost effectiveness of LED and existing conventional luminaires (high pressure sodium (HPS) and metal halide (MH)). Photometric measurements of the lamps and the luminaires were performed at Yıldız Technical University Lighting Laboratory in Turkey. The performance requirements of the luminaires were analysed according to CIE (International Commission on Illumination) standards. In the simulations, HPS, MH and LED luminaires that provide good lighting criteria for designing M1 and M2 road models were compared in terms of a cost analysis. The life cycle cost analysis (LCCA) method, which comprises installation, energy and maintenance costs, was used in this study. The results of the LCCA showed that LED luminaires have almost the same cost effectiveness as HPS luminaires for the M2 road lighting class, and the total cost of LED luminaires is approximately 11.5 % less than that of HPS luminaires for the M1 lighting class.

Keywords: roadway lighting, LED luminaire, energy efficiency, life cycle cost

1. INTRODUCTION

Worldwide, environmental impacts and energy security issues due to increasing energy consumption have been serious problems since the energy crisis in the 1970s. Globally, lighting consumes approximately 19 % of the total generated electricity [1]. Also, it is estimated that approximately (3–4) % of total generated electricity is used for road lighting around the world [1]. Lighting being a significant consumer of electricity worldwide, energy efficiency improvements in this field can lead to significant reductions in total energy consumption [2].

Significant amount of investments are done in energy efficient lighting to reduce energy costs and CO_2 emissions. Replacing traditional lighting with energy efficient light emitting diode (LED) – based lighting has the potential to reduce green house gas (GHG) emissions by 670 MT annually and decrease energy costs by (50–70)% [3]. Many studies have shown that retrofitted projects in lighting applications could reduce energy costs up to 50 % by employing state-of-the-art lighting technologies [4, 5].

LED light sources are good alternatives for road lighting over traditional sources due to their colour properties, uniform light distribution, improved mesopic vision, controllability, and low environmental impacts [6][7]. Moreover, the illuminance level can be controlled to adapt to variations in the road surface reflectance, traffic density and weather conditions to reduce energy consumption without affecting the lifetime of luminaire [8, 9]. The environmental impact (e.g. acidification, climate change, eutrophication, human toxicity) of LED luminaires per kilometre of lit road is forecasted to be 41 % less than that of HPS luminaires due to reduced energy consumption by 2020 [10].

The life cycle cost analysis method can be used to determine the best choice for an investment decision. This method enables one to determine the profitability of an investment in the road lighting [11, 12]. The LCCA is suitable to determine the lowest cost among alternative installations and to analyse the profitability of a projected investment. Various studies have carried out life cycle cost analysis of conventional luminaires [13, 14]. The lower life cycle cost should be obtained with higher-lifetime products that have low energy consumption (high luminous efficacy) and purchasing price [15]. The LCCA by Tähkämö et al. presents different scenarios based on predicted average electricity price and luminous efficacy of LED luminaire and, so, the payback time of LED luminaires can be reduced in the next years [14]. The results of study, in which LED luminaires were used for M3 road lighting class in Turkey, showed that LED luminaires can provide the lighting quality criteria for M3 road lighting class and can be comparable with conventional luminaires [13]. In addition, some studies include life cycle assessment (LCA) to evaluate environmental impacts of luminaire technologies and road construction [10, 16].

In this study, all sample luminaires are examined for compliance of road lighting requirements. The conventional and LED luminaires are then compared in terms of life cycle costs for M1 and M2 road lighting class. Road lighting classes are defined in terms of speed, traffic volume, weather, traffic composition, intersection density, separation of carriageways, parked vehicles, ambient luminance and visual guidance in the CIE publication [17]. The LCCA method includes installation, maintenance, replacement, energy and salvage costs.

The paper is organized as follows: the methodology and design calculations of road models are presented in Section 2. The description of the life cycle cost analyses is given in Section 3. The results of cost analyses are discussed in Section 4 and conclusions are drawn in Section 5.

2. METHODOLOGY AND DESIGN CALCULATIONS OF ROAD MODELS

This study adopted several methods in three steps to find the most appropriate M1 and M2 class road luminaires to be installed and maintained with the lowest life cycle cost in Turkey. The block diagram of the methodology is given in Fig. 1.

Firstly, HPS, MH and LED road luminaires were procured from six different manufacturers (L1, L2, L3, L4, L5 and L6). There were six conventional luminaires from three different manufacturers and six LED luminaires. The conventional luminaires had HPS (150 W Philips SON-T and 250 W Philips SON-T) and MH (150 W Sylvania CMI and 250 W Philips HPI-T) light sources. The powers of LED luminaires ranged from 80 W to 170 W. The photometric quantities of these twelve luminaires were measured in the Yıldız Technical University Lighting Laboratory in Turkey by using an integrating sphere and goniophotometer. The quantities measured include luminous flux, luminous intensity distribution, maximum light intensity, maximum light angle, luminous efficacy, power, power factor, CIE general colour rendering index (CRI) and correlated colour temperature (CCT).

Secondly, the results of the measurements were saved as EULUMDAT files and transferred to the DIALux lighting design software package. The road models were simulated based on M1 and M2 lighting classes and optimized the most suitable road design. The HPS, MH and LED luminaires that provided minimum road lighting requirements were determined for LCCA.

Finally, according to the results of the design calculations, cost analyses of the HPS and MH luminaires were calculated with the LCCA method. After that, the lowest-life-cycle-cost HPS (150 W L3 for M2 and 250 W L3 for M1) and MH (150 W L3 for M2 and 250 W L1 for M1) luminaires and all LED luminaires were analysed to compare the life cycle costs of the luminaires. Installation, maintenance and energy costs were calculated using recent prices in Turkey. The HPS and MH luminaires completed their lifetime at the end of the project (about 30 years), so salvage costs were not considered in this study. In contrast, salvage costs were considered for the LED luminaires due to the unused period of the luminaire lifetime.

2.1. Measurement Equipment and Photometric Data

The HPS and MH lamps were first measured with an integrating sphere (Everfine Photo-E-Info Co., Ltd.). The lamps were seasoned for 100 operating hours before they were tested [18]. The lamps were measured with ballast and igniter of the luminaire, and the luminous flux, CCT and CRI were obtained. The CCT of HPS and MH lamps ranged from 2039 K to 2083 K and from 4062 K to 4127

Table 1. Photometric Data of Conventional Luminaires

No	Luminaire type	Measured Power, W*	Power factor	Luminous flux, lm	Luminous efficacy, lm/W	Max. radiation angle, grad (C, γ)	Luminous intensity curve type
1	150W HPS L1	166.0	0.939	13,087	78.8	5;24	limited
2	150W HPS L2	174.9	0.951	13,824	79.0	320;18	unlimited
3	150W HPS L3	148.6	0.930	12,579	84.7	145;19	semi-limited
4	150W MH L1	163.5	0.939	9,554	58.4	180;58	limited
5	150W MH L2	169.7	0.942	9,392	55.3	185;67	unlimited
6	150W MH L3	148.8	0.931	9,398	63.1	10;64	semi-limited
7	250W HPS L1	278.6	0.772	26,227	94.1	15;31	limited
8	250W HPS L2	263.7	0.950	23,224	88.1	345;48	limited
9	250W HPS L3	234.5	0.951	21,524	91.8	200;14	semi-limited
10	250W MH L1	296.1	0.641	20,966	70.8	155;25	semi-limited
11	250W MH L2	277.6	0.858	18,132	65.3	355;64	limited
12	250W MH L3	263.2	0.844	17,784	67.6	350;66	unlimited

** It is included ballast losses.*
L1, L2, L3, L4, L5, L6: Names of various road luminaires manufacturers.

K respectively. The CRI of HPS and MH lamps ranged from 28.7 to 29.6 and from 62.3 to 65.1 respectively. The CCT and CRI of LED luminaires ranged from 4000 K to 4500 K and from 70 to 80 respectively. After the lamp luminous flux was measured using the sphere, the luminous intensity distribution of the luminaires, luminaire luminous flux and it's efficacy were determined using goniophotometer (Everfine Photo-E-Info Co., Ltd.) measurements.

The LED light sources were integrated in LED luminaires without a replaceable LED module. Therefore, the LED luminaires were only measured with the goniophotometer. Moreover, the LED luminaires were tested without seasoning. It should be noted, that the light output of some LEDs can increase slightly during the first 1000 h of operation, but many LED sources do not exhibit similar behaviour [19]. The temperature and humidity of the laboratory were maintained at 25±1 °C and 65 % respectively, with the help of an air condition unit. The luminous intensity of these luminaries was measured at 5° intervals in the range of (0–355)°, yielding 72 different C planes, and the γ angle was sampled at 1° intervals in the range of (0–90) ° for each C plane. The results of photometric and electrical measurement of the luminaire samples are shown in Tables 1 and 2.

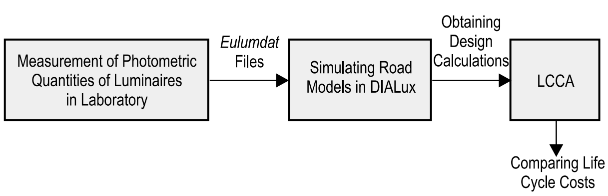


Fig. 1. Block diagram of the methodology

In Table 1, about 67 % of luminaires have power factors greater than 0.90. The luminous efficacy varies between 55.35 and 94.14 lm/W.

As can be observed from Table 2, the measured power is almost the same as the nominal power for different LED luminaires. The power factor of all LED luminaires is better than that of conventional luminaires. The luminous efficacy of LED luminaires varies between 78.77 and 122.34 lm/W.

2.2. Design Calculations Using the DIALux Lighting Design Program

Each sample luminaire has a different luminous intensity distribution; thus, the road lighting design has to take into account different characteristics to satisfy road lighting criteria [20]. When using different luminaires, design calculations such as pole spacing, montage height, tilt angle, and overhang

Table 2. Photometric Data of LED Luminaires

No	Luminaire type	Measured power, W	Power factor	Luminous flux, lm	Luminous efficacy, lm/W	Max. radiation angle, grad (C, γ)	Luminous intensity curve type
1	80W LED L1	79.35	0.984	7,392	93.1	180;63	limited
2	80W LED L4	79.9	0.934	8,654	108.3	45;49	semi-limited
3	105W LED L4	105.3	0.964	11,503	109.2	135;50	semi-limited
4	114W LED L5	112.6	0.980	8,869	78.8	160;60	semi-limited
5	170W LED L3	163.6	0.972	15,331	93.7	15;61	limited
6	153W LED L6	152.5	0.987	18,656	122.3	155;67	unlimited

differ from each other. Road lighting design should be optimized based on the maximum pole spacing.

According to the minimum road lighting quality criteria, the maximum pole spacing (*s*) was calculated using DIALux for the M1 and M2 road lighting classes. Other design parameters, such as the mounting height (*mh*), overhang (*oh*) and luminaire arm angle (θ), were determined according to the performance requirements.

2.2.1. Road Design for the M2 Lighting Class

The road model was simulated to assign lighting quality criteria to the luminaires. In general, 150 W HPS and MH luminaires are used for the M2 and M3 road lighting classes [21]. In this simulation, 150 W HPS and MH luminaires from three different manufacturers (L1, L2 and L3) and LED luminaires (80 W-114 W) from three different manufacturers (L1, L4 and L5) were used for the M2 lighting class. The road geometry and designed road model for the M2 lighting class are shown in Fig. 2a.

The road model consists of a four-lane divided road. The width of each lane is 3.5 m. The road model is illuminated with the luminaires placed opposite one another, i.e., in an opposite arrangement. This lighting situation is evaluated as A1 on a motorway on which the typical speed of a motorized vehicle user is greater than 60 km/h. The road surface used is the R3 pavement class. The luminaire maintenance factor considered is 0.89 [22].

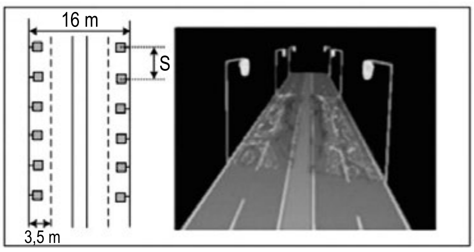
2.2.2. Road Design for the M1 Lighting Class

In the roads with M1 and M2 lighting classes, 250 W HPS and MH luminaires are commonly used. In this simulation, the M1 lighting class is selected and simulated as three lanes on both side. The width of each lane is 3.5 m. The lighting design is defined with the median arrangement in the A1 lighting situation. The road surface pavement type and maintenance factor are R3 and 0.89 respectively. The road geometry and designed road model for M1 lighting class are given in Fig. 2b.

The HPS and MH luminaires (250 W) from three different manufacturers (L1, L2 and L3) and two types of LED luminaires from two different manufacturers (L3 and L6) are simulated for the M1 lighting class.

2.2.3. Results of the Road Design Calculations

The results of the road design calculations for the M1 and M2 lighting classes are in DIALux. As-



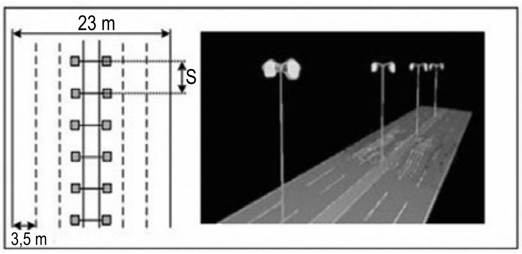


Fig. 2. Road Geometry: a) M2 Lighting Class, b) M1 Lighting Class

Table 3. Properties of Used Luminaires for LCCA in M2 Lighting Class

No	Luminaire type	Number of luminaires (piece/km)	Poles number (piece/km)	Lamp lifetime (h)	Replacement cycles (Year)	Price of luminaire (TL/piece)	Price of lamp (TL/ piece)
1	150W HPS L3	58	58	20,000	5	140.00	33.00
2	150W MH L3	72	72	12,000	3	140.00	33.00
3	80W LED L1	74	74	50,000	13	420.00	-
4	80W LED L4	74	74	50,000	13	470.00	-
5	105W LED L4	64	64	50,000	13	530.00	-
6	114W LED L5	64	64	50,000	13	630.00	-

Table 4. Properties of Used Luminaires for LCCA in M1 Lighting Class

No	Luminaire type	Number of luminaires (piece/km)	Poles number (piece/km)	Lamp lifetime (h)	Replacement cycles (Year)	Price of luminaire (TL/piece)	Price of lamp (TL/ piece)
1	250W HPS L3	64	32	20,000	5	212.00	45.00
2	250W MH L1	68	34	12,000	3	212.00	45.00
3	170W LED L3	76	38	50,000	13	400.00	-
4	153W LED L6	68	34	50,000	13	550.00	-

sociated with luminaire glare, the threshold increment of 150 W L2 luminaire does not comply with the requirement of ≤10 for the M2 road class.

The L1 HPS luminaire had a maximum pole spacing of 36 m, and the installed power of the L1 luminaire is calculated to be 9,296 W/km. The L3 HPS luminaire consumes 8,619 W/km at a pole spacing of 35 m. In this case, the number of L1 luminaires per km is less than that of L3 luminaires, so the installation and maintenance costs will be less. On the other hand, the energy cost per km of the L3 luminaire is less than that of the L1 luminaire. Therefore, the total cost of the L1 and L3 luminaires (HPS and MH) should be calculated based on LCCA to determine the most cost-effective luminaire.

In terms of energy consumption per km, LED luminaires are the most advantageous. However, installation and maintenance costs should also be examined to compare conventional and LED luminaires. The cost calculations and analysis of the luminaires for the M2 road lighting class are performed in Section 3.

3. LIFE CYCLE COST ANALYSIS (LCCA)

The life cycle cost analysis includes the installation, maintenance, replacement, operation and salvage costs over the project lifetime. The net present value (NPV) is used to determine the present value of an investment, so all costs are converted into their present values in the LCCA method. The equation (1) for the NPV total cost used in this study, considers both inflation and the interest rate.

$$NPV = \sum_{k=1}^{30} A * \frac{(1+e)^k}{(1+i)^k}, \tag{1}$$

where A is the present cost, e is the inflation rate, i is the interest rate, k is the years.

First, the costs of the conventional luminaires were compared between themselves according to the LCCA method. After the cost analyses, the HPS and MH luminaires with the minimum total cost were selected. The 150 W HPS and 250 W HPS luminaires produced by manufacturer L3 have the minimum total cost compared with other HPS lu-

Table 5. Results of NPV Total Costs for M2 Lighting Class

No	Luminaire type	Initial cost, TL/km	Energy cost, TL/km	Maintenance cost, TL/km	Salvage value, TL/km	Total cost, TL/km
1	150W HPS L3	154,976.00	173,473.47	11,379.34	-	339,828.82
2	150W MH L3	168,588.00	215,636.21	22,956.06	-	407,180.28
3	80W LED L1	194,139.00	118,111.23	41,683.97	12,670.98	341,263.22
4	80W LED L4	191,734.00	119,004.88	52,888.19	14,179.43	349,447.64
5	105W LED L4	183,712.00	135,255.69	50,740.32	13,828.82	355,879.19
6	114W LED L5	186,944.00	145,045.62	58,943.61	16,438.03	374,495.21

Table 6. Results of NPV Total Costs for M1 Lighting Class

No	Luminaire type	Initial cost, TL/km	Energy cost, TL/km	Maintenance cost, TL/km	Salvage value, TL/km	Total cost, TL/km
1	250W HPS L3	96,704.00	302,071.04	16,322.06	-	415,097.10
2	250W MH L1	99,297.00	405,259.86	28,077.40	-	532,634.26
3	170W LED L3	116,698.00	250,255.23	47,483.18	12,393.76	402,042.65
4	153W LED L6	115,515.00	208,720.46	55,619.08	15,247.58	364,606.96

minaires. Similarly, 150 W MH L3 and 250 W MH L1 luminaires have lower LCCs than other MH luminaires. However, all LED luminaires are incorporated in the LCCA. As mentioned in Section 2.2, the properties of the analyzed luminaires for the M1 and M2 lighting class are listed in Tables 3 and 4. LCCA considers the costs of lighting installation over its entire project life (generally 30 years in road lighting) [14]. The project life is assumed to be 30 years in this analysis, with a road lighting annual operation time of 3,650 hours. The economic life of conventional luminaires is 30 years, and these luminaires are not replaced with new luminaires during this time. Replacement cycle is lamp replacement year for conventional luminaire and luminaire replacement year for LEDs.

On the other hand, LED systems are considered as a whole (including the module, driver, lens, etc.), so the lifetime of the luminaire is determined based on the components of the LED system. The lifetime of the driver is less than the LED source lifetime [23]. More than 90 % of LED systems fail because of the driver [23]. Currently, there is no standard for the replaceable parts of LED luminaires. Luminaire manufacturers urgently note that the lighting industry should improve standardized drivers for use in LED lighting [23]. When luminaire failure occurs individually in road lighting, the replacement and maintenance are more expensive and hence avoided by cities [24]. To achieve more economical and feasible maintenance, the lamps in street lighting luminaires are replaced via group replacements rather than spot replacement. In this study, the components of the LED luminaire (such as the driver and the LED module/light source) are not replaced during the time period but the replacement scheme of LED luminaires considers the entire LED luminaires to be replaced after their use of expected lifetime.

According to LCCA, subtracting the salvage value (SV) from the sum of the installation cost (IC), energy cost (EC) and maintenance cost (MC) yields the total cost (TC) [11]. Cost calculations are made for a per kilometre road lighting investment, and equations are given below. The salvage value is calculated for the unused period of replacement products during the economic lifetime. In other words, only the final replaced LED luminaires over the project lifetime have salvage value. The environmental waste of luminaires and components are recycled for free of charge by municipality in Turkey, so the disposal costs were not considered in the LCCA in this study.

$$TC = IC + MC + EC - SV, \quad (2)$$

$$IC = N*\left(N_p + N_{mp}\right) + L*\left(L_p + L_{mp}\right) + \\ + P*\left(P_p + P_{mp}\right) + C*\left(C_p + C_{mp}\right) + \\ + YC*\left(YC_p + YC_{mp}\right), \quad (3)$$

$$MC = L*\left(L_p + L_{mp}\right) + \\ + \left(S_n * S_p + F_p\right) * N / \left(S * t_d\right), \quad (4)$$

$$EC = N * P_i * 365 * E_p * 10^{-3} * t_o, \quad (5)$$

where N is the number of luminaire, N_p is the price of a luminaire, N_{mp} is the luminaire mounting price, L is the number of lamp, L_p is the price of a lamp, L_{mp} is the lamp mounting price, P is the number of pole, P_p is the price of a pole, P_{mp} is the pole mounting price, C is the cable length, C_p is the cable price per metre, C_{mp} is the cable mounting price per metre, YC is the underground cable length, YC_p is the underground cable price per metre, YC_{mp} is the underground cable mounting price per meter, S is the number of luminaires maintained in an hour, S_n is the number of maintenance staff, S_p is the daily price of staff, F_p is the fuel price of vehicle per day, t_d is the daily working time, P_i is the power of the luminaire, E_p is the energy unit price per kWh, t_o is the daily operation time of luminaire.

Maintenance, energy and salvage costs are calculated with the NPV method [13]. The maintenance cost is separately calculated for every replacement period and then the total maintenance cost is obtained according to NPV method. The replacement cost of electromagnetic ballast is also added to equation (4) for the conventional luminaires. The present value of the total energy cost in the project lifetime is calculated using the following equation [25, 26]:

$$\text{Total Energy Present Value} = \\ = \text{EC}*(1+\text{e})*\frac{1-\left(\frac{1+\text{e}}{1+\text{i}}\right)^{30}}{\text{i}-\text{e}}. \quad (6)$$

In this study, the unit of currency used is the Turkish Lira (TL). In contrast with European countries, high interest and inflation rates are used in Turkey, so these rates should be considered for long-time economic investment analysis. The interest (i) and inflation rates (e) of the Turkish Central Bank are considered in the calculations because the luminaires are utilized for road lighting in Turkey. The average inflation and interest rate are taken to be 8.5 % and 10.5 % respectively [27, 28]. The prices of luminaires are obtained from daily luminaire catalogues of manufacturers. Other labour and mounting costs are defined based on recent prices in Turkey.

Maintenance costs for conventional luminaires comprises re-lamping, replacement ballast and cleaning of luminaires. When the lamp is replaced, cleaning of luminaires is also conducted. The replacement of electromagnetic ballast is done two times in project life. The prices of 150 W and 250 W electromagnetic ballasts are 32.00 and 43.00 TL/piece, respectively. Conventional luminaires are assumed to not be replaced during the 30-year lifetime. On the other hand, LED luminaires are accepted as integrated LED luminaire, so re-lamping is not considered for LED luminaires. The lifetime of LED luminaires average 50,000 hours, and the replacement time is calculated to be 13.7 years. LED luminaires are replaced twice in 30 years. These dates of replacement were approximately assumed as 13 and 27 of years. Moreover, maintenance of LED luminaires is performed once every 5 years. The maintenance cost in (4) also depends on staff costs, fuel costs, operation time and number of lamps. Two laborers re-lamp and maintain ten luminaires in an hour. The daily cost for staff and daily working time are 80.00 TL/day and 8 hours, respectively. The daily fuel cost of a vehicle for transportation is 150.00 TL/day. The daily operation time of luminaires is assumed to be 10 hours, and the total annual operating time is 3,650 hours. The unit electrical energy cost for lighting is 0.257 TL/kWh in Turkey. The calculation of the energy cost is shown in equation (5).

The installation cost in equation (3) consists of the lamp, pole, cable, labour and luminaire costs. The numbers of luminaires and poles per km were calculated using the DIALux lighting design program. The price of a pole with accessories averages 750.00 TL/piece, and the pole mounting price is 10.00 TL/meter (of pole height). The prices of the mounting luminaire and lamp are 75.00 and 5.00 TL/piece respectively. The cable cost is calculated for both overhead and underground cables. The underground cable length is calculated by multiplying of the pole numbers with the pole spacing; overhead cable length is calculated by multiplying the mounting height of a luminaire by the number of poles per km. The underground cable and mounting prices are 7.50 and 35.00 TL/m respectively. The overhead cable and mounting prices are 4.50 and 2.00 TL/m respectively.

The salvage value is calculated for the last replaced LED luminaries. If the economic analysis period (project life) is assumed to be 30 years, a LED luminaire will be used for 13.7 years assuming an annual operation time of 3,650 hours and LED luminaire lifetime of 50,000 hours. LED luminaires should be replaced with new ones at the end of 50,000 hours. The last replacement luminaire is thus used only 2.6 years. In this situation, the salvage value of the unused period of the luminaire lifetime should be calculated. Thus, the salvage value is subtracted from the total cost due to the serviceable time of the LED luminaire. When the second replacement is performed, the calculation of the unused rate of the luminaire is shown in (7) [11].

$$100\times\left(1-\frac{30-(2\times 13.7)}{13.7}\right)=81\%. \quad (7)$$

During the project lifetime, 81 % of the lifetime of the last replaced LED luminaire is not used. If luminaire price is 470.00 TL, the salvage value of the last replaced LED luminaire is calculated to be 470.00 TL*0.81=370.70 TL. This value will depend on the inflation and interest rate in the future, so equation (1) is used to calculate the present value of the salvage value.

4. RESULTS OF COST ANALYSES

The life cost cycle analyses of the luminaires are defined for an operation time of 30 years. The NPV of the total cost includes the installation, energy, and maintenance costs and salvage value. The cost results of luminaires per km for the M2 and M1 road classes are listed in Tables 5 and 6.

According to Table 5, HPS L3 and LED L1 luminaires have almost the same life cycle cost and are more cost effective luminaires for the M2 road class. Whereas the energy cost of the HPS L3 luminaire is approximately 32 % greater than that of the LED L1 luminaire, the initial cost of HPS L3 luminaires is approximately 20 % less than that of the LED L1 luminaire. The maintenance cost includes replacement of the whole luminaire for LEDs, but it includes only lamp replacement for conventional luminaires. Therefore, the maintenance costs of LED luminaires are greater than those of conventional luminaires. The MH luminaire has the greatest total cost due to its low efficacy (lm/W) and short lamp lifetime.

According to the results presented in Table 6, the LED L6 luminaire is the most profitable investment compared with other luminaires for the M1 lighting class. Although the number of LED L6 luminaires per km (68 / km) is greater than that of conventional luminaires (64 / km), the energy cost of LED L6 luminaires is less than that of the others because of the high luminaire efficacy. Additionally, the electromagnetic ballast losses of conventional luminaires cause significant energy consumption. The energy and total costs of MH luminaires are approximately 48.5 % and 31 % respectively and are greater than those of the LED L6 luminaire.

5. CONCLUSIONS

In this study, the photometric values of conventional and LED luminaires that belong to the M1 and M2 road lighting classes were measured in the laboratory. Design calculations were performed using the DIALux software package to optimize the maximum pole spacing while satisfying the minimum road lighting criteria for different road lighting classes. The most cost-effective conventional luminaires were compared with state-of-the-art LED luminaires using the LCCA method, which considers the installation, energy, maintenance costs and salvage value.

The LCCA calculations show that the 80 W LED L3 and 150 W HPS L1 luminaires have almost the same cost effectiveness for a new road lighting application assuming a 30-year operation time and the M2 road lighting class. However, using LED luminaires can be more beneficial considering energy savings, CO_2 emissions due to power plants and lighting quality. MH luminaires have the highest total cost for the M1 and M2 road lighting classes. On the other hand, 153 W LED L6 luminaires have lower total cost than the 250 W HPS and MH luminaires in the M1 road lighting class. In all categories, the installation costs of LED luminaires are greater due to their luminaire price, whereas the energy costs of LED luminaires are less than those of conventional luminaires.

This study also shows the importance of comparisons of different luminaire technologies (HPS, MH, and LED) in terms of energy savings, lighting quality, and cost effectiveness. According to the results, the cost effectiveness of LED systems particularly depends on two key parameters: the price of electricity and the price of the luminaire. In the future, LEDs will be more commonly used as the price of the luminaire keeps decreasing. If the price of electricity increases due to depletion of oil resources, LED luminaires will be more advantageous economically for roadway lighting.

ACKNOWLEDGMENT

The authors would like to thank The Scientific and Technological Research Council of Turkey (TUBITAK) and Scientific Research Project Coordination of Yıldız Technical University (YTU-BAPK-Grand Number: 2015–04–02-KAP01) for the financial support during the duration of this study.

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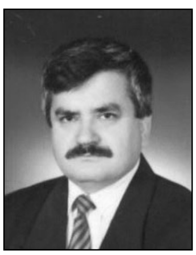

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