Light & Engineering
Vol. 27, No. 3, pp. 67–74, 2019 *https://doi.org/10.33383/2018 - 066*

COMPARISON OF LED AND HPS LUMINAIRES IN TERMS OF ENERGY SAVINGS AT TUNNEL ILLUMINATION

Behçet Kocaman and Sabir Rüstemli

Bitlis Eren University, Bitlis, Turkey
E-mail: bkocaman@beu.edu.tr; srustemli@beu.edu.tr

ABSTRACT

Energy demand is increasing day by day because of the step-up of population, rising living standards, rising energy prices, global warming and climate change, developments in industry and technology in developing countries. In order to meet this increasing energy demand, it is not possible to increase production only due to limited energy resources. Therefore existing energy sources need to be used in the most efficient way. One of the most important means of reaching this target is the efficient use of energy and its saving. Tunnel illumination is one of the areas of efficient and saving use of energy. In this study, high-pressure sodium (HPS) and light emitting diode (LED) luminaires usage are compared to Buzlupınar tunnel, which is a short tunnel in Bitlis province. It has also been found that illumination with LED luminaires is more efficient and economical in tunnel illumination instead of HPS.

Keywords: tunnel illumination, LED, HPS, energy saving

1. INTRODUCTION

Turkey is a country with limited resources in terms of energy resources. In other words, the country does not have adequate energy resources to meet the energy demand growth. It is a country that depends on outsiders, who can provide about a quarter of its energy needs from its own resources and the rest from external sources. Basic target should be to provide energy needs, adequate, reliable and economical, to getting rid of external dependency.

Tunnels are constructed on the pedestrian road, railway, highway, canal, etc. in a situation, where it is technically impossible for the roads to pass through the earth or in order to pass underground a part of the way to arrange the traffic flow in the city or outside the city. It is necessary to illuminate the tunnels with artificial lighting during the day as well as at night using different designs and techniques. The main purpose of tunnel illumination is to provide the right comfort and safety while the driver is in the tunnel, passes inside the tunnel, and exits the tunnel.

These two points are of great importance in night illumination in the tunnels. Nowadays illumination and energy efficiency are gaining importance. As technology develops, the need for information on how illumination products are tested, with which methods and which standards are used, is increasing day by day. Levels of illumination in the tunnel begin to be revised from a lighting installation, which combines extensive research and existing technologies to develop a solution with visibility and security [1]. Luminaires are designed by taking into account the intensities of exhaust and other gases that pollute the air inside the tunnels. Stainless materials, especially steel and hardened glass lens materials, are durable to corrosion.

The distances between the luminaires are important, and illumination equipment needs to be positioned more tightly than if it is based on aesthetic considerations. Different types of electric lu-

minaires such as HPS, mercury vapour, and LED are used in tunnel illumination.

Generally, tunnel projects using long-life illumination elements are provided with more fluorescent luminaires and LED selections. The choice of illumination colours, suitable for improved traffic safety, must be specific to the architecture of the tunnel. Therefore illumination should be designed differently on the inside of the tunnel, differently towards the exit of the tunnel [2].

Tunnel in terms of illumination can be classified into two types like short and long tunnels. The short tunnels appear as "dark frames" in the field of view. In a flat tunnel, the observation area is approximately 20 meters when looking at an obstacle of 100 meters distance to 20 cm height. Considering the contributions of daylight at the entrance and exit, the length of the straight tunnel, which does not require daylighting, can be accepted as 50 meters. Short tunnels do not need illumination in the daytime. However, when the tunnel is bend or ramp or where traffic intensity is too much that is shorter than this length may also need illumination in daytime [3].

The model of a tunnel with two tubes is shown in Fig. 1. As shown in figure 1, the tunnel is divided into 4 zones such as access, entrance, interior, and exit.

The access zone is a part of the road immediately outside the tunnel, in which an approaching driver must be able to recognize a possible obstacle. Its length is equal to the stopping distance. In the entrance zone, luminance levels decrease slowly in order to allow the adaptation of the driver's eyes to the lower lighting levels featuring the interior zone. The interior zone is a part located between the transition zone and the exit zone. Luminance levels should guarantee a safe drive. The exit zone is a terminal part of the tunnel, where the visibility is influenced by the external luminance. In some cases, adaptive lighting can be required.

2. THE IMPORTANCE OF TUNNEL ILLUMINATION

Good illumination of the tunnels is extremely important in terms of the safety and comfort of the passengers. In addition, appropriate illumination solutions and used suitable luminaires for tunnel construction provide energy efficiency. Correct illumination provides not only luminous adaptation to the environment when the drivers enter the tunnel but also the driver's confidence sense to travel in the tunnel.

A tunnel, which has inadequate illumination, leads to the impression of a "black hole" for an impending driver, and the driver suffers a loss of sight [4]. Tunnels need to be illuminated gradually in order to prevent drivers' visibility loss in the tunnel. A tunnel road is a relatively enclosed space where the illumination suddenly alters from bright to dark ("black hole") at the entrance of the tunnel and from dark to bright light ("bright hole") at the exit of the tunnel as shown in Fig. 2.

Light sources used in tunnel illumination must have certain characteristics. These are the higher the efficiency factor, long life span and the luminaire can be used easily in it.

Light sources need to be used with suitable luminaires for a correct illumination. The luminaires to be used in the tunnel illumination must have the following characteristics [3]:

- Being economical;
- Must be installed easily and easy to maintain;

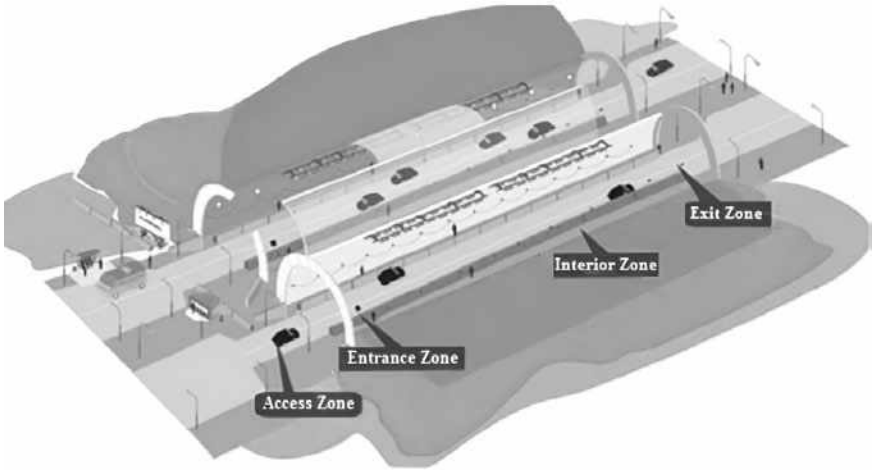

Fig. 1. The model of a tunnel with two tubes

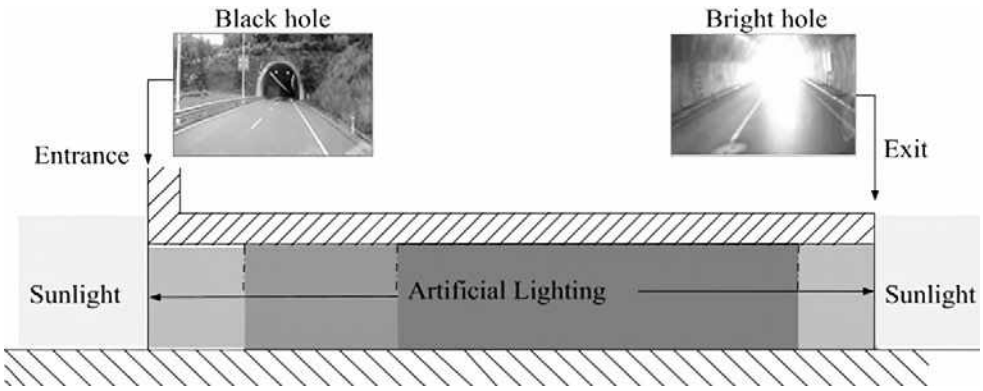

Fig. 2. A tunnel with black and bright hole

- Prevent glare;
- Waterproof against pressured water, durable to detergent and corrosion;
- Controlling the light distribution curve of the bare lamp and giving it the desired light distribution curve shape;
- Be adaptable to SCADA programs which are used with developing technology in tunnels;
- Providing visual guidance.

The luminous efficacy of the lamp chosen in the illumination is very important in terms of economic efficiency. The luminous efficacy is the rate of conversion of the electrical energy drawn from the network to the light.

2.1. Luminaires Used in Tunnel Illumination

Different types of electric luminaires are used in tunnel illumination such as fluorescent, low/high-pressure sodium vapour, mercury vapour, and LED luminaires. LEDs from these luminaires have begun to become more preferred in tunnel illumination in recent years, due to their efficiency and longer life span and easier maintenance than other luminaires. For this reason, it is important to replace the HPS luminaires with LED luminaires, which are used to minimize the energy consumption in the tunnels.

2.2. High-Pressure Sodium Luminaires

High-pressure sodium (HPS) luminaires, a member of the high-intensity discharge (HID) lamp family, are the most efficient white light source commercially available today. HPS luminaires feature highly energy efficient performance with a very long life by comparison to other conventional luminaires. HPS luminaire is one of the luminaires used in tunnel illumination. In these luminaires, the discharge tube is placed in a hard glass balloon in the form of an evacuated tube.

The characteristic features of HPS luminaires are long-life span, provides high luminous efficacy, low maintenance costs, for outside and inside illumination use, universal operating position, resistant against changes in voltage, used together with assistant elements.

2.3. Light Emitting Diode (LED) Luminaires

The light in the LED luminaires is generated by electron movements in a semiconductor structure. When starting to design LED luminaires, firstly, the lighting criteria should be determined from the standards and proposals that must be provided in the lighting installations intended to be used with the luminaire. Then luminaire design objectives must be determined in suitable with these criteria. LED luminaires require different optical solutions for LED light sources and suitable luminaire designs due to small in size relative to conventional light sources. LED luminaires for a tunnel are available. Today, the usage areas and technical characteristics of LED luminaires are developing with technology every passing day [5]. It has the following advantages:

- Solid light source;
- No pollution, no ultraviolet;
- High colour rendering index;
- Continuous illumination control by adjusting the electric current and the control speed is fast, almost instantaneous;
- Through the design of a dedicated communication controller, each luminaire status, fault information, and the continuous adjustment of illumination are available [6].

In recent years, along with improvements in technology, control systems and the use of LED

Fig. 3. Two tube views of the Buzlupınar tunnel

Fig. 4. Illumination of the Buzlupınar tunnel using HPS luminaires

luminaires have made great improvements in tunnel illumination. Today, however, most of the tunnels are illuminated by high-pressure sodium-vapour or mercury-vapour luminaires, which consume more energy [7]. For this reason, LED luminaires should be used to provide significant energy saving and efficient solutions for tunnel illumination.

LED luminaires should be preferred in the tunnels for the following reasons:

- Achieve high energy efficiency;
- At 25ºC their luminous efficacy is at least 130 lm/W;
- Easy and diverse designs can easily be made thanks to the minimal size of an LED chip;
- They quickly enter the mode;
- They are easy to install and maintain as they are not made of fragile elements such as glass or filaments;
- Do not cause sound vibrations to be heard with the human ear because they work with DC current;
- They are environmentally safe, as they don't contain heavy metals such as mercury;
- It has flicker-free light features;
- They can be used safely because they are luminaires, which do not give very high heat like gas discharge luminaires;
- If any LED source fails in the luminaire, it is short-circuited. In this case, the luminaire continues to light. There is not a huge change in the homogeneity of the illumination until the number of broken LED sources reaches a certain amount;
- The improvements in LED optical design can easily be made symmetrical, asymmetrical;
- LED luminaires can detect objects in their true colour because of the Colour Rendering Index (CRI) values are about 70 [8].

3. TUNNEL ILLUMINATION APPLICATION

The Buzlupınar tunnel is located on Bitlis-Diyarbakır highway, at the coordinates of 38°17'48" north and 41°59'52" east. Buzlupınar tunnel by General Directorate of Highways within the borders of Bitlis province. It is made of two tubes for two directions of traffic (Fig. 3).

However, this study was analysed using the right tube data. The total length of the right tube is 233 meters. This tunnel is one of Turkey's first highway tunnel illumination with LED luminaires. The energy quantities of HPS and LED luminaires when used were analysed in the tunnel illumination. Comparison of LED luminaire and HPS luminaire are given in Table 1.

In this study, the cost and energy savings will be analysed considering the costs of investment and the power consumption of the LED luminaires instead of the HPS luminaires using the same energy source. Moreover, comparison of LED and HPS luminaires in terms of energy saving in tunnel illumination was done for daily illumination. The number of HPS luminaires, lamp power, ballast power, and total power consumed in the Buzlupınar tunnel are given in Table 2.

According to the amount of light needed to enter the tunnel, HPS luminaires are phased in gradually. In total, there are 6 steps, which are: all of the luminaires are on, 75 % of the luminaires are on, 50 % of the luminaires are on, 25 % of the luminaires are on, night mode, and emergency illumination. Emergency illumination is only used in energy interruptions and is supplied by the uninterrupted power supply. The power, uptimes, and daily-consumed energy of the HPS luminaires used ac-

Table 1. Comparison of LED and HPS Luminaires

Characteristics	HPS Luminaires	LED Luminaires
Power (W)	100–500	43–170
Dimmability	Requires special ballast	Yes
Dimming limit	50 %	10 %
Luminous efficacy (lm/W)	80–140	114–160
Lifetime in hours (×1000)	10–24	100+
Mercury content	~6 mg/100 W	0
Warm up time (minutes)	2–15	Instant
Restrike time (minutes)	4–5	Instant
Operating temperature (°C)	-30 to 65	-55 to 70

Table 2. Used HPS Luminaires Values

Power of HPS luminaires (W)	Number of luminaires used	Ballast Power (W)	Total Power (W)
70	168	13	13944
150	28	26	4928
250	20	35	5700
400	120	50	54000
Total			78572

cording to their steps in the tunnel in one day are given in Table 3.

As shown in Table 3, uptimes of HPS luminaires are 2.75 h in step 1, 1.33 h in step 2, 1.50 h in step 3, 1.25 h in step 4, 17.17 h in step 5 in one day. The daily consumed energy of the HPS luminaires is 637,012.08 Wh (637.01 kWh).

Illumination of the Buzlupınar tunnel using HPS luminaires is given in Fig. 4.

The number of LED luminaires used in Buzlupınar tunnel, the luminaire power, the ballast power, and the total power consumed are given in Table 4.

LED luminaires are used in steps as they are in HPS luminaires. However, the emergency illumination step is not available in LED applications. For this reason, LED luminaires are used in 5 steps and in comparative 6th step calculations are not included.

The power, uptimes, and daily-consumed energy of the LED luminaires used according to their steps in the tunnel in one day are given in Table 5.

As shown in Table 5, uptimes of LED luminaires are 2.75 h in step 1, 1.33 h in step 2, 1.50 h in step 3, 1.25 h in step 4, 17.17 h in step 5 in one day. Moreover as shown in Table 5, the daily-consumed energy of the LED luminaire is 380,230.50 Wh (380.23 kWh).

Illumination of the Buzlupınar tunnel using an LED luminaires are given in Fig. 5.

4. COMPARISON OF LED AND HPS LUMINAIRES AT TUNNEL ILLUMINATION

On average, the power spent on daily illumination with a day HPS luminaires is 637.01 kWh, while with a day LED luminaires is 380.23 kWh.

The advantages of the use of the LED luminaires instead of the HPS luminaires in the tunnel are:

- Daily average energy saving is (637.01–380.23) kWh = 256.78 kWh/day;
- Monthly average energy saving is 256.78 kWh/day × 30 day = 7703.4 kWh/month;
- Annual average energy saving is 7703.4 kWh/month × 12 month = 92440.8 kWh/year.

According to the Republic of Turkey Energy Market Regulatory tariff, the general illumination applied since 01.04.2018 the unit price of elec-

Table 3. Daily Consumed Energy of HPS Luminaires

HPS	Power of HPS luminaire (W)	Number of luminaires used	Ballast Power (W)	Total Power (W)	Time (h)	Daily Consumed Energy (Wh)
Step 1	70	168	13	13944	2.75	38346.00
	150	28	26	4928	2.75	13552.00
	250	20	35	5700	2.75	15675.00
	400	120	50	54000	2.75	148500.00
Step 2	70	168	13	13944	1.33	18545.52
	150	16	26	2816	1.33	3745.28
	250	16	35	4560	1.33	6064.80
	400	88	50	39600	1.33	52668.00
Step 3	70	168	13	13944	1.50	20916.00
	150	4	26	704	1.50	1056.00
	250	8	35	2280	1.50	3420.00
	400	60	50	27000	1.50	40500.00
Step 4	70	168	13	13944	1.25	17430.00
	150	0	26	0	1.25	0.00
	250	4	35	1140	1.25	1425.00
	400	28	50	12600	1.25	15750.00
Step 5	70	168	13	13944	17.17	239418.48
	150	0	26	0	17.17	0.00
	250	0	35	0	17.17	0.00
	400	0	50	0	17.17	0.00
Step 6	Used only in emergencies (eg power interruption)					
	Total Daily Consumed Energy (Wh)					637012.08

tric energy is 0.346747 TL / kWh. According to this, in the case of using the LED luminaire for daily illumination of the tunnel, one-year energy cost is saved: 92440.8 kWh × 0.346747 TL / kWh = 32053.57 TL.

Fig. 5. Illumination of the Buzlupınar tunnel using LED luminaires

The prices of luminaires and ballasts used in tunnel illumination vary from mark to mark, while labour prices vary from company to company. From this point of view, an average value is determined from the firms in the internet, market research is carried out, and the cost account is given as in Tables 6–7.

The same workmanship is calculated for HPS and LED luminaires used in tunnel illumination. For this reason, montage workmanship did not participate in the account. According to the calculations made, the cost for HPS luminaires was 415,200 TL and 715,400 TL for LED luminaires. The investment made with LED luminaire is (715,400–415200) TL = 300,200 TL more in terms of initial installation cost. However, LED luminaires save 32053.57 TL per year.

According to these values, the LED illumination instead of HPS will pay off in 9.37 years

Table 4. Used LED Luminaire Values

Lamp type / LED driver	Number of luminaires used (Number)	Power of luminaires (W)	Total power (W)
96 LED500 mA	30	153	4590
96 LED700 mA	166	213	35358
		Total	39948

Table 5. Daily Consumed Energy of LED Luminaires

LED	Power of LED luminaire (W)	Number of luminaires used	Total Power (W)	Uptime (h)	Daily Consumed Energy (Wh)
Step 1	153	30	4590	2.75	12622.50
	213	166	35358	2.75	97234.50
Step 2	153	8	1224	1.33	1627.92
	213	166	35358	1.33	47026.14
Step 3	153	8	1224	1.50	1836.00
	213	126	26838	1.50	40257.00
Step 4	153	8	1224	1.25	1530.00
	213	80	17040	1.25	21300.00
Step 5	153	4	612	17.17	10508.04
	213	40	8520	17.17	146288.40
Total Daily Consumed Energy (Wh)					380230.50

Table 6. Cost Accounting of HPS Luminaires

HPS luminaire Power (W)	Luminaire Unit Price (TL)	Ballast Unit Price (TL)	The number of Luminaire / Ballast	Total Price (TL)
70	930	80	168	169680
150	1200	65	28	35420
250	1250	75	20	26500
400	1400	130	120	183600
			Total	415200

(300,200 TL / 32,053.57 TL), and it will be cheaper to use in the following years. This study was done for a 233-meter tunnel. However, in longer tunnels, this time will shorten.

5. CONCLUSION

The creation of efficient illumination systems in the tunnels requires good luminaire design and use of control systems. The luminaire design, which can be controlled from a centralized system with technological and low power consumption, should be developed. In addition, in order to prevent darkness of the tunnels, it is necessary to consider an illumination circuit to be switched on in case of an emergency. Therefore, besides the network, it needs to be fed from a 3-phase generator, which will be switched on in case of necessity.

LED illumination is more advantageous since it does not require frequent maintenance and it is more energy-efficient than the conventional luminaires. These luminaires should be used to provide significant energy saving and efficient solutions for tunnel illumination. For this reason, it is important

Table 7. Cost accounting of LED Luminaires

LED Luminaire Type	Luminaire Unit Price (TL)	The number of Luminaire	Total Price (TL)
96 LED500 mA	3650	30	109500
96 LED700 mA	3650	166	605900
		Generally Total	715400

to replace the HPS luminaires with LED luminaires, which are used to minimize the energy consumption in the tunnels.

Daily illumination of the Buzlupınar tunnel in Bitlis province was compared with HPS and LED luminaire usage. This study was done for daily illumination in it. When the tunnel is made with LED luminaire instead of HPS luminaire, energy saving of 256.78 kWh per day is achieved. This savings are calculated to provide 92440.8 kWh of energy savings on a yearly basis. This is why it is very advantageous for energy saving. In the calculation made, the LED luminaire will be amortized within 9.37 years, although the initial cost of the LED luminaire is higher than the HPS luminaire. This study was done for a 233 meters tunnel. The calculated time for amortization can be a little long. However, this time will shorten in longer tunnels. The maintenance of the luminaires used in the tunnel is a separate expenditure. LED luminaires have little maintenance cost compared to HPS luminaires. This is a major advantage of LED luminaires. In addition, LED luminaire lifespan is more than other luminaires. Therefore, care should be taken to make tunnels with less energy-consuming LED luminaires.

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Behçet Kocaman, Ph.D. in Electrical Engineering, Kocaeli University. Assistant Professor at department of Electrical and Electronic Engineering at Bitlis Eren University. His research areas are energy efficiency, illumination, renewable energy sources, energy management and transmission and distribution technologies

Sabir Rüstemli, Ph.D. in Electrical Engineering, Azerbaijan Scientific-Research Institute of Electric. He became Associate Professor in 1997 and Professor in 2005. Chairman of Electrical-Electronics Engineering and also Vice Rector in Bitlis Eren University