A Status of Energy Efficient LED Based Traffic Lamps in Istanbul

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Abstract. Recently, the energy resources have been decreased while the global energy demand is expected to grow rapidly. This has led the authorities associated with traffic management to seek various solutions for enhancing energy efficiency of the huge numbers of lamps used in traffic light systems. Hence, many metropolitan areas, like Istanbul, have started using traffic lights equipped with LEDs instead of the conventional incandescent bulbs. The energy saving, low maintenance costs, traffic and road security improvements all contribute to an environment friendly and economical configuration. In this paper, the (R&D) department at ISBAK Inc., demonstrates the benefits of switching the old-style incandescent bulbs to the LED based lamps in traffic signalization system at Istanbul as a case study that will may be useful for other municipalities and researchers. The comparison tables for power consumption show the contribution of LED based traffic lights in Istanbul to the national economy and environment.

Keywords: Energy savings · LED based traffic lamps · Incandescent bulbs · Traffic safety

1 Introduction

Over the last few years, the global energy shortages have been rapidly increased; where, on the other hand, the global energy demand is set to grow by 37 % by 2040 as the International Energy Agency (IEA) mentioned in world energy outlook 2014 [1]. Conventional traffic lights contain bulky and powerful lamps where these lamps consume a lot of amount of electrical power that are not efficient enough according to the currently energy saving standards. Recently, important governmental policies and standards were announced in order to efficiently utilize the electricity during the design process of the lighting equipment [2,3]. In order to save energy, cities switched the conventional bulbs in traffic lights to LED based traffic lamps.

LED is a solid state optoelectronic semiconductor which converts most of the input electrical power directly to light. Historically, in 1907, the British electrical engineer and experimenter Captain Henry J. Round published his observations

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on a curious phenomenon where a yellowish light was emitted when he applied a certain voltage on the carborundum or Silicon Carbide (SIC) crystals [4,5]. In 1962, the first red luminescence diode (type GaAsP), developed by American Nick Holonyak, enters the market where it has been remarked as the birth of the industrially-produced LED. Indeed, Energy efficiency, long life, resistance to shock and vibration, less heat production and design flexibility are the main outstanding features of LEDs. LED technology was first used in traffic light at 1990 in the United States as the red lights in foggy road conditions for truck routes. At 1994 in Japan, the bluish-green LED was produced and the traffic applications, which based on LED technology, have been established in 1995 [5].

In 1998, the research and development department at ISBAK Inc. (Istanbul Telecommunication Transportation and Security Technologies), which is an affiliated company to Istanbul Metropolitan Municipality, started to follow this new technology in the designing process of the traffic lamps. The early products based on LED technology for road intersections at Istanbul had been achieved in 2000. Based on the European standard for Traffic_Control_Equipment_Signal_Heads EN 12368:2000 and the revised versions in 2006 and 2015 [6–8], Turkish Standards Institute (TSE) published the Traffic_Control_Equipment_Signal_Lamps Standard TS EN 12368 with the up-to-date version in October 2015 [9]. The R&D group at ISBAK Inc. follows this standard during the developing and fabricating process of the LED based traffic signal lamps. Actually, European standard EN 12368 includes all types of lamps used in traffic control equipment (incandescent, halogen, LED) where some issues related to the LED based traffic lamps are not specified at this standard. For this reason, the R&D department in ISBAK Inc. used some rules, in addition to European standard, from the American Standard ITE (Institute of Transportation Engineers) that focus only on LED based traffic lamps [10]. At the end of 2006, the all traditional traffic bulbs in Istanbul have been switched to LED based lamps. ISBAK Inc. successfully developed and produced 200–300 mm diameter LED based traffic lamps within a TEYDEB (Technology and Innovation Funding Programs Directorate) Project in 2006.

From the literature, the authors in [2] at 2002 introduce the expected economic effects, energy saving, and the main features in rep. of Korea when the conventional traffic signal lamps will be replaced by the Korean-type LED traffic signal; they expected an energy saving effect of 85 % and drop of 75 % in maintenance fee. In 2001, the City of Portland, USA, replaced most of its incandescent traffic signal lights with highly efficient LED based lamps. Using an innovative leasing arrangement to amortize the investment costs, Portlands Signal and Street Lighting Division was able to replace 13,382 red and green existing incandescent lamps with LED based lamps. The project resulted in 4.9 million kilowatt-hours (kWh) of annual savings in energy consumption (representing an 80 % reduction in energy usage), and a reduction of about 2,880 tons of annual CO_2 emissions [11]. In this paper, the contributions of 76869 traffic signal modules in 2101 signalized intersections in Istanbul(February 2016) to the national economy, energy saving and environmental protection are analyzed. The rest of

Fig. 1. The yellow incandescent bulbs and LED based lamps produced by ISBAK Inc. (Color figure online)

Table 1. Features and advantages of LEDs.

Feature	Advantages
Semiconductor light source	Cost-effective solutions
	Design flexibility
	Bright and strong light
Low power consumption	Electrical power savings
	Low heat generation
	Applicable to the use of solar energy
High reliability	Wide MTBF (mean time between possible failure)
	Wide operating temperature range
	Not deteriorate by burning
Long operating life	low light loss in long-term operation
	No need for frequently lamp replacement
	Low maintenances

this paper is organized as follows. In Sect. 2, a brief comparison between the LED based traffic lamps and the old-style incandescent bulbs is illustrated. The contributions of LED based traffic lamps to energy saving are explained in Sect. 3. Section 4 describes the other contributions in road safety and environmental protection; then the disadvantages of LED based traffic lamps are discussed. Finally, some conclusions are drawn in Sect. 5.

2 Comparison of LED Based Traffic Lights with Incandescent Bulbs

LED based traffic lights use 80 to 90 percent less energy and last around ten times longer than traditional incandescent bulbs that put out the same amount of light [12]. Furthermore, LEDs resist the mechanical shocks and vibrations due to their robust and non-glass outer covers which made of plastic capsule material. For vibration resist, there are no copper Fleming wires inside LEDs as in incandescent bulbs. Moreover, LED superior the incandescent bulb in that it

Table 2. Differences in power consumption between the yellow old-style incandescent and LED based traffic lamps.

Function	Yellow Incandescent	Yellow LED
300 mm Yellow Ball	100 W	12.500 W
300 mm Yellow Flash	100 W	12.500 W
300 mm Yellow Arrow	100 W	8.170 W

has the resistance capability to the most weather conditions as heat, humidity and winds. A general list of features and advantages of LEDs light sources are given in Table 1. Table 2 illustrates the difference in power consumption between the 300 mm yellow old-style incandescent bulbs and the 300 mm LEDs based lamps for various products. Figure 1 shows the bulb and LEDs based lamp which produced by ISBAK Inc.

Conventional incandescent lamps require color filters to provide the desired color of light, which causes a large amount of wasted electricity that is not used in light producing. In contrast, LED based traffic lamps can be designed to directly produce light as the required color. Another important advance for LEDs is the long-term effects; for 5 mm LEDs, which used in traffic lamps, the forward current should be between 10 mA and 30 mA in order to obtain a long-term and good performance working hours. In AlInGaP LEDs, operating 10,000 h under 30 mA current value leads to approximately 20 % reduction of starting luminous flux while this reduction of luminous flux will be 10 % in case of 20mA operating current. After 50000 operating hours there will be approximately 25 % reduction of luminous flux in case of 20mA forward current. For same case, the luminous flux will reduces to the half of the starting one after 100,000 h (about 11 years). On the other hand, the luminous flux of incandescent traffic bulbs, which have a life time of 8–10 thousand hours, reduces to the half of the starting value

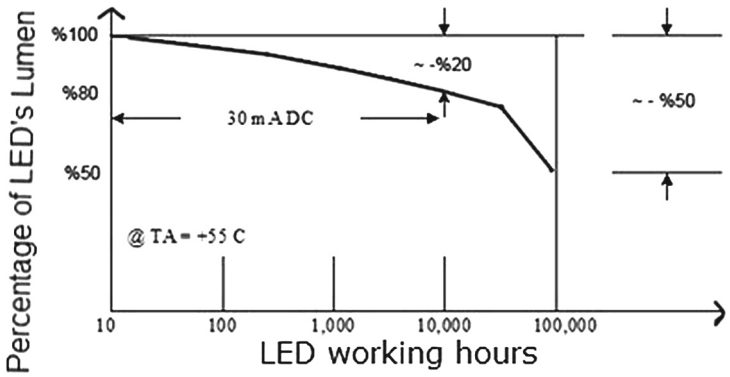

Fig. 2. LED lumen depreciation.

after only 1500 h of operating. Because the lumen depreciation is very little for LED based lamps, there is no need to change the lamps as much as in old-style incandescent ones which leads to a remarkable minimization in the maintenance costs. Figure 2 illustrates the lumen depreciation phenomenon of LED. The Min. Light intensity (cd) of LEDs used in traffic light and their light wave length (nm) are demonstrated in Table 3.

Table 3. Technical data of LEDs based traffic lamps designed in ISBAK Inc.

Operating voltage (230 VAC)	200 mm.			300 mm.		
Signal color	Red	Yellow	Green	Red	Yellow	Green
Min. Light intensity (cd)	200	200	200	400	400	400
Typ. Light wave length (nm)	630	592	505	630	592	505

3 Contributions of LED Based Traffic Lamps to Energy Saving

In the light of these benefits of LEDs, which mentioned at previous section, the ministry of transportation in Turkey has prepared a regulation based on Article 7 of the Law of Energy Efficiency No. 5627 dated 18.04.2007 for the improvement of energy efficiency. According to this regulation, it was reported that LED based systems will be given priority for traffic signalization to regulate the flow of traffic and to reduce the energy consumption in the signaling system and these lamps should be designed in accordance with TS EN 12368 standard [3]. Furthermore, within the framework of "Improvement of Energy Efficiency in Turkey Matching Project Twinning Project", which started in July 2005, studies carried out with the energy efficiency of organizations at France and Netherlands, ADEME and SenterNovem in order to establish energy efficiency concept in Turkey which is appropriate to their counterparts in Europe. In this context, project activities are conducted under the three main components; strengthening the legal and institutional structures, determination of potential energy savings and identifying barriers [13]. In 2006, the R&D group in ISBAK Inc. replaced all the old-style bulbs for the traffic light system with new LED based traffic lamps version. Figure 3 shows some of ISBAK Inc. products that currently used in Istanbul. Power consumption and energy saving comparison case study has been done at the R&D department in ISBAK Inc. between the LED based traffic lamps and the incandescent bulbs which used in Istanbul traffic light intersection. The average operating times for traffic lamps of the intersections in Istanbul is illustrated in Table 4. Tables 5, 6 and 7 summarize the results of this study.

Notes:

- 1 kWh energy = 0,311494 Turkish Lira (₺) with the taxes are excluded from this price; this energy cost is taken from the list of TEDAS-Turkish electric distribution company for 2016 [14].

Fig. 3. LED based lamps produced by ISBAK Inc at Istanbul city.

Table 4. Average operating times for traffic lamps of the intersections in Istanbul.

Traffic unit	Red lamp	Yellow lamp	Green lamp	Flash lamp	Red pedestrian	Green pedestrian
Operating time percentage	53.9%	2.2%	43.9%	50%	59.1%	40.9%

Table 5. Energy consumption of incandescent bulbs previously used in Istanbul.

Lamp type	Pow. cons. (watt)	Number of modules in Istanbul	Average operating time per hour (hours)	Annual pow. Cons. (kWh)	Annual cost(₺)
300 mm Red Lamp	100	5664	0.539	2,674,336.90	833,039.90
300 mm Yellow Lamp	100	5664	0.022	109,156.61	34,001.63
300 mm Green Lamp	100	5664	0.439	2,178,170.50	678,487.04
300 mm Flash Lamp	100	1399	0.50	612,762.00	190,871.69
200 mm Red Lamp	75	9789	0.539	3,466,510.05	1,079,797.08
200 mm Yellow Lamp	75	9789	0.022	141,490.21	44,073.35
200 mm Green Lamp	75	9789	0.439	2,823,372.75	879,463.67
200 mm Flash Lamp	75	228	0.50	74,898.00	23,330.28
200 mm Red Pedestrian	75	11221	0.591	4,356,968.43	1,357,169.52
200 mm Green Pedestrian	75	11221	0.409	3,015,228.57	939,225.61
300 mm Red Arrow	100	292	0.539	137,871.89	42,946.27
300 mm Yellow Arrow	100	292	0.022	5,627.42	1,752.91
300 mm Green Arrow	100	292	0.439	112,292.69	34,978.50
200 mm Red Arrow	75	1855	0.539	656,898.17	204,619.84
200 mm Yellow Arrow	75	1855	0.022	26,812.17	8,351.83
200 mm Green Arrow	75	1855	0.439	535,024.67	166,656.97
Total		76869		20,927,421.00	6,518,766.08

- The currency exchange rate between dollar and Turkish Lira (Turkish Central Bank 09.02.2016) is 1$ = 2,9471₺
- Pow. Cons. Is the abbreviation of Power Consumption factor.

From Table 7, the total annual Energy Savings is about 89 %. Hence, approximately two million dollars of annual energy savings were achieved by switching

Table 6. Energy consumption of LEDs based Traffic lamps in Istanbul.

Lamp type	Pow. cons. (watt)	Number of modules in Istanbul	Average operating time per hour (hours)	Annual pow. Cons. (kWh)	Annual cost(₺)
300 mm Red Lamp	14.440	5664	0.539	386,174.25	120,290.96
300 mm Yellow Lamp	12.500	5664	0.022	13,644.58	4,250.20
300 mm Green Lamp	10.420	5664	0.439	226,965.37	70,698.35
300 mm Flash Lamp	12.500	1399	0.50	76,595.25	23,858.96
200 mm Red Lamp	7.964	9789	0.539	368,097.15	114,660.05
200 mm Yellow Lamp	7.608	9789	0.022	14,352.77	4,470.80
200 mm Green Lamp	7.854	9789	0.439	295,663.59	92,097.44
200 mm Flash Lamp	7.608	228	0.50	7,597.65	2,366.62
200 mm Red Pedestrian	8.202	11221	0.591	476,478.07	148,420.06
200 mm Green Pedestrian	8.062	11221	0.409	324,116.97	100,960.49
300 mm Red Arrow	7.440	292	0.539	10,257.67	3,195.20
300 mm Yellow Arrow	8.170	292	0.022	459.76	143.21
300 mm Green Arrow	8.610	292	0.439	9,668.40	3,011.65
200 mm Red Arrow	6.180	1855	0.539	54,128.41	16,860.67
200 mm Yellow Arrow	6.570	1855	0.022	2,348.75	731.62
200 mm Green Arrow	6.580	1855	0.439	46,939.50	14,621.37
Total		76869		2,313,488.12	720,637.67

Table 7. Annual energy savings with LED lamps.

	Incandescent lamps	LED lamps	Annual savings
Annual Pow. Cons. kWh	20,927,421.00	2,313,488.12	18,613,932.88 kWh
Annual Energy Costs ($)	2,211,925.65	244,524.34	1,967,401.31 ($)

all incandescent traffic bulbs in Istanbul to LED based traffic lamps. Moreover, the maintenance costs reduce by 91 % with LED based traffic lamps due to the statistics result which show that just only 5 % of LED based lamps are broken down once a year; on the other hand, the incandescent lamps are changed due to breaking or due to the loss of luminous flux in every 6 months for overhead traffic lamps. When only the energy costs are considered, the amortization period is 2.2 years for an LED based lamps. However, this period will reduce to be 1.5 years in case of the maintenance costs are supplemented.

4 Other Properties for LED Based Traffic Lamps

4.1 Contributions of LED Based Traffic Lights to Traffic and Road Safety

Indeed, the human eyes have best response to light sources with saturated color. Hence, the drivers can effectively distinguish the saturated color LED based light in comparing to the other light sources under the bright sunlight. Moreover, LED based lamp has the best light source which can be seen by the drivers in adverse

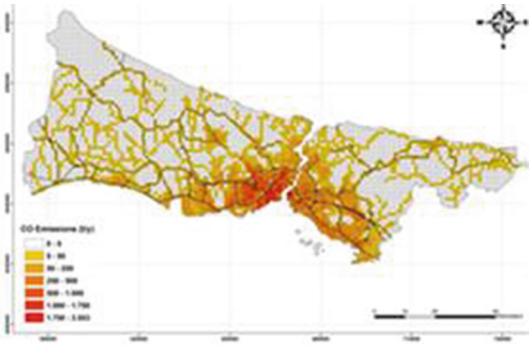

Fig. 4. CO_2 emissions of Istanbul [17].

weather conditions and can easily recognize other distracting light sources on the opposite road lane. Furthermore, the color of the LED light source does not change due to dimming. Previously, reflectors and colored lenses are used in the signal units with conventional signal lamps. But the sunrays are coming with horizontal angles especially in the morning and evening rush-hours; hence, drivers cannot easily perceive the color of the traffic light due to the reflections from the reflector of the traffic lights (phantom light) in east-west direction. LED traffic signal lights get their colors from LEDs where the colored lenses and reflectors are not used.Hence, these advantages of LED based traffic lights will decrease the numbers of accidents in the cities.

4.2 Contribution of LED Based Traffic Lights to the Environmental Protection

Turkey, taking part in some activities related to environmental protection, such as the Kyoto Protocol which is taking steps to ensure the international fight against global warming and climate change. Countries that signed the Kyoto Protocol in scope of United Nations Climate Change Framework Agreement, promised to reduce the re-lease of carbon dioxide and five other gases that cause the greenhouse effect or if they cannot they promised to improve their rights through emissions trade. The protocol was signed in 1997 and came into force in 2005. The Kyoto Protocol currently includes 160 countries on Earth and more than 55 % of their greenhouse gas emissions. Turkey has been included in the protocol on February 5th 2009 [15]. LED based traffic lights can be considered to be environmental solutions for their energy saving potential. According to statistics of International Energy Agency (IES) in 2013, 459.582 grams of CO_2 emissions are released to produce 1 kWh electric energy in Turkey. 8555 tons/year of CO_2 emissions are prevented by 18614 MWh energy savings. Figure 4 show the CO_2 emissions of Istanbul. For comparison, when the most frequently used automobiles in Turkey are taken into consideration, an average automobile releases 2725 kg CO_2 when it travels averagely 15000 Km per year [16]. Which means

Fig. 5. Heavy snow conditions cover the LED based traffic lamps.

green-house gas emissions would be prevented equivalent to 3139 automobiles withdrawn from traffic.

4.3 Disadvantages of LED Based Traffic Lamps

Nowadays, LEDs are more expensive than conventional lighting source technologies due to their initial cost. Although the payback time for the LED based traffic lamps (about 1.5 years) decreases every passing year, the initial cost of LEDs based traffic lamps is still higher comparing to incandescent/halogen bulbs. Historically, payback time was 3, 3.5 years due to the leakages in technology at the early LED based traffic lamps at 1995. In areas with heavy snow conditions, another disadvantage for the LED based lamps is appeared; Since LEDs produce a very little amount of heat which is not enough to melt the snow accumulated on lamps outer lens. In this case, drivers cant recognize clearly the state of lamps which cause to somehow a case of traffic chaos as shown in Fig. 5. Moreover, some electronics expertise is needed to design electronic drivers in order to supply the correct polarity, voltage and current at a constant flow.

5 Conclusion

Usage of LED based signal lamps is rapidly increasing all over the world due to the noticeable increase in the light efficiency of LEDs, energy-saving, ease of maintenance, their long life times and other benefits. Indeed, installation costs of LEDs are higher than incandescent lamps; however, the energy consumption is decreased by 89 %, the maintenance costs are decreased by 91 % and the payback time for the LED based traffic lamps is about 1.5 years. In this paper, The research and development department (R&D) at ISBAK Inc. (Istanbul Telecommunication Transportation and Security Technologies), which is an affiliated company to Istanbul Metropolitan Municipality, demonstrates the benefits of switching the old-style incandescent bulbs to the LED based lamps in traffic signalization system at Istanbul. Contribution of total 76869 traffic signal modules

in 2101 signalized intersections in Istanbul (February 2016) to the national economy is explained. Approximately two million dollars of annual energy savings were achieved by switching all incandescent traffic bulbs in Istanbul to LEDs based traffic lamps and 8555 tons/year of CO_2 emissions are prevented by 18614 MWh energy saving. In Turkey, which has approximately 9,000 intersections, if all traffic signal lights are switched to LED based lamps systems then it is clear that significant energy savings, environmental protection and the maximum safety in traffic will be provided. Furthermore, within the context of government policy and energy-saving practice, the transition to LED lighting with remote control and automation applications to reduce the level of illuminance in urban and general lighting, is on the agenda of ISBAK Inc. For that, ISBAK inc. and Istanbul Technical University (ITU), developing a common project, with the support of Ministry of Science Industry and Technology (MoSIT), established a test road in Istanbul, ITU Ayazaga Campus where different road conditions and scenarios can be practiced in order to assess and measure the visual performance of drivers. According to the measurements and experimental results which will be held on the test road, it is aimed to develop a road lighting automation system working with correct dimming scenarios [18]. As a future work, we will also constraint on the low voltage systems (< 42 VAC)for traffic light which provide an important feature of traffic signaling due to the better monitoring and the increased safety for the engineers working on the traffic signals at the street.

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