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ADVANCEMENT IN ROAD LIGHTING

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ABSTRACT

Road lighting is on the verge of one of the most attentive changes since its first introduction. The synergetic effect of the advancement of road lighting technology and usage pattern is going to change the concept of road lighting. By most estimates, light emitting diodes (LEDs) are the most energy efficient light sources that can be used in road lighting. Today, the energy saving potential when replacing HPS lamps with LED luminaires is one-third with current technology and two-thirds with improved technology in the future. This technological transformation has the potential of energy saving up to 83 % in comparison with HPS lamps. The energy saving is achievable with changing the pattern of use by intelligent road lighting control based on reducing burning hours. Intelligent road lighting can be based on such parameters as traffic density, ambient light, road condition and weather circumstances. It can also be more dynamic and consider the combined effect of road lighting and individual car headlights. The widespread adaptation of these emerging technologies is envisioned to lead towards more sustainable lighting.

Keywords: energy efficiency, LED, light source, traffic safety, road lighting, sustainability

1. INTRODUCTION

Road lighting is undeniably essential for road users to observe obstacles, decide ahead and avoid accidents. At the same time, it is becoming difficult to ignore the energy consumption and electricity costs related to the road lighting. The International Energy Agency has evaluated that in 2005, 19 % of the total global electricity consumption was used for lighting in which road lighting used 218 TWh amounting to about 8 % of lighting electricity consumption [1].

The electricity costs can be reduced by technological advancement and modification in the pattern of use via utilisation of intelligent road lighting. Lighting technologies have developed from gas lamp to incandescent, fluorescent, mercury vapour, low-pressure sodium, high-pressure sodium, and metal halide. Currently, LED technology is emerging as a new light source technology. These transitions have improved the efficiency and cost saving as well as lifespan, colour properties, dimming ability, and run-up and reignition times of road lighting [2].

It is evident that energy efficiency plays an important role in the transition of road lighting. However, there is still potential to reduce electricity consumption by dimming road lighting when and where needed based on real-time demand and by modifying the pattern of use (with intelligent road lighting systems).

Transition to new road lighting technologies and pattern of use have several benefits, such as reduction of electrical energy, costs, and maintenance, and provision of more environmentally friendly solutions. However, it is critical to acknowledge the purpose of road lighting before making any decisions to invest in new road lighting sources or making them intelligent. The primary goal of road lighting is to improve safety by increasing visibility of roadside hazards and by reducing the effects of glare from other light sources in the visual environment [3]. Many studies have shown that road lighting can mitigate nighttime accidents [4, 5, 6]. Therefore, it is essential to have an overview of advancements in road lighting.

The current paper is originated from Tetri et al. (2017) [2], where the authors' scope was broad and considered multiple aspects of road lighting such as mesopic vision, visibility and safety and 3D modelling of the lighting environment. Here the study is more focused on road lighting technology, traffic safety, and sustainability. In this article, we address the effect of road lighting on traffic safety, the benefits of using LEDs, and the effect of road lighting advancements on sustainability. By addressing the recent technological development, we describe how the road lighting technologies are changing and debate the future concept of road lighting.

2. TRAFFIC SAFETY

According to World Health Organization, over 1.2 million people were killed in road accidents in 2015, which makes it one of the 10 major causes of death in the world [7]. Generally, human (57 %), roadway (3 %) and vehicle factors (3 %) are causing traffic accidents; the rest is due to their interactions [8].

Difficulties arise, however, when an attempt is made to study the effect of one factor such as road lighting on accidents. Firstly, many interacting variables affect accidents, which make the separation of the effect of road lighting difficult [8]. Secondly, drivers' behaviour changes before and after installations of road lighting. For instance, Assum et al. [9] investigated drivers' behavioural adaptations in relation to speed and concentration before and after installation of road lighting in Norway. As a consequence of the installation of road lighting, increase in the number of older drivers, increase in speed and decrease in concentration was evident. Therefore, these interacting factors affect the accuracy of the effect of road lighting on accidents [9].

In order to measure the effect of road lighting on accidents, the comparison of accident data either on the areas where road lighting did not previously exist and is then introduced or where improvements have been made to road lighting has to be conducted. This can be done with an odd ratio, which is a metric for quantifying the effect of road lighting on accidents.

$$\begin{gathered}\text{Odd ratio} = \\ = \frac{(\text{№ accidents in darkness on lit roads})}{(\text{№ accidents in darkness on unlit roads})} + \\ + \frac{(\text{№ accidents in daylighting on lit roads}}{(\text{№ accidents in daylighting on unlit roads})}\,. \end{gathered} \tag{1}$$

Road lighting has been identified as a contributing factor to the decline of traffic accidents. A number of studies have shown that road lighting can reduce nighttime accidents [4, 6, 10]. A well-known example of this is a study by International Commission on Illumination (CIE) [4]; they found that the average effect of road lighting installation on the reduction of accidents was 30 %.

The increasing trend of using intelligent road lighting [2, 9, 11] has already drawn attention to study the effect of quality of road lighting on accident [12,13,14]. A study by Gibbons et al. [15] indicated that current road lighting practices result in over-lighting and the increased lighting level does not necessarily lead to a safer road. They studied the relationship between lighting level and lighting quality and accidents based on the night-to-day crash rate ratio. The study concluded that current road lighting practices are over-lighted and there is a potential to reduce road lighting levels by as much as 50 % for the urban interstate functional class. In addition, Steinbach et al. studied the effect of reduced road lighting on traffic safety and crime prevention [16]. The results provide no evidence that switching off, part-night light, and dimming adaptations to the road lighting were associated with night-time traffic accidents. Also, there was no evidence of increasing crime in these conditions during the hours of darkness. Therefore, the relevance of dimming road lighting without adversely affecting traffic safety is supported by the findings.

3. LIGHTING TECHNOLOGY

3.1. Changes in Technology

In 2005, IEA estimated that 62 % of total outdoor light was provided by high-pressure sodium (HPS) and low-pressure sodium (LPS) lamps, 30 %

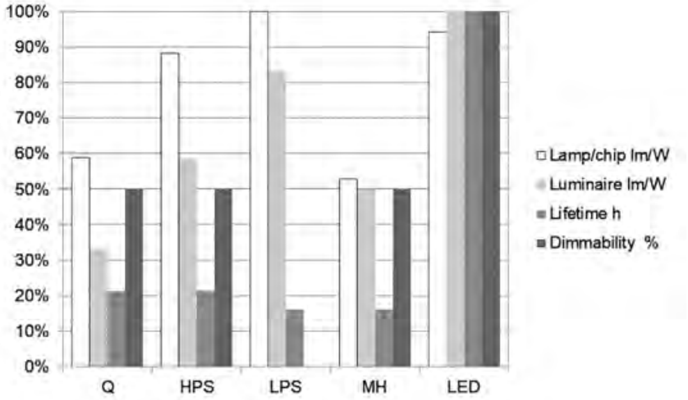

Fig.1. Characteristics of different lamp/luminaire types when compared to the 100 % reference values, which are: LPS lamp luminous efficacy 170 lm/W, LED luminaire luminous efficacy 120 lm/W, lifetime 75000 h (LED), and dimmability 100 % (LED)

by mercury vapour (Q) lamps, 6 % by metal halide (MH) lamps and the remaining 2 % mostly by halogen and incandescent lamps [1].

HPS, Q and MH lamps are also known as high-intensity discharge (HID) lamps. The light-producing element of these lamp types is an arc discharge. Each type of HID lamp produces light related to the type of metal that is contained in the arc. HID lamps have negative volt-ampere characteristics, and therefore a current-limiting device is needed, usually a ballast. They also need auxiliaries for starting. They have commonly few minutes' run-up time before the operation light output level is reached. Often, they also need few minutes to cool down, before the arc ignition can work. HPS lamps can be dimmed to roughly 50 % light level by adjusting the supply voltage. Q and HPS lamps have often 4-year group replacement period, giving them 16000 h lamp life. LPS and MH lamps have commonly 12000 hours' lamp life. Luminous efficacy is highest with LPS lamps (150–170) lm/W. HPS lamps have an efficacy of (80–150) lm/W, Q lamps (40–60) lm/W and MH lamps (60–90) lm/W. Efficacies are dependent on lamp power and colour rendering properties. For instance, with HPS lamps the increase of the pressure and temperature inside the arc tube increases the colour rendering and colour temperature, but decreases the efficacy.

Like mentioned above, the luminous efficacy of a HPS lamp can be 150 lm/W [17]. However, when a lamp is placed in a luminaire, the luminaire efficiency (lumen output ratio) decreases the total efficacy. Luminaire efficiencies are often quite low, especially with old luminaires [18]. When the luminaire efficiency and ballast losses are taken into account, the luminaire luminous efficacy is often about 40 lm/W [19]. Characteristics of different lamp and luminaire types are compared in Fig. 1.

HID lamps are based on gas discharge, whereas LEDs are semiconductors. The wavelength of the radiation depends on the semiconductor material. In road lighting, it is common to use blue radiation chips. Some of the blue radiation is then turned to longer wavelengths with a phosphor coating. There is no infrared radiation in the spectra and the excess heat of the LED junction has to be conducted to heat sink [20]. Without adequate heat sinking (or ventilation), the junction temperature will rise, resulting in lower light output and reduced lifetime. Unlike with discharge lamps, there is no few minutes run-up or re-strike time. The light output is instant after the switch-on. The rise time of LED light output is less than microseconds [21]. The rise time does not limit the use of LEDs in dimming use. The power is almost linear with luminous flux and thus the luminous efficacy remains high also in dimming use.

LED luminaires are very long-lasting, according to manufacturer data their service life can be from 50000 to 100 00 hours. The status of luminous efficacy is already higher 100 lm/W for LED luminaires [22]. However, the semiconductor material and phosphor coating can degenerate in use and thus reduce the lifetime, especially in warm environments.

3.2. Control of Light

Significant development is occurring in the area of road lighting control. The lighting control system can be adjusted in real time or according to a predefined time-schedule. The latter being called intelligent road lighting [12]. The most widely used control system is photoelectric cells that switch lights on/off based on the availability of daylight. Due to the low cost and reliability of photoelectric cells, they can be applied to individual luminaires or groups of luminaires. Currently, the most widely used photoelectric cells have the factory setting of the switch on at 70 lx as the natural lighting levels fall at dusk and off at 35 lx as the lighting levels increase at dawn. However, the operating range can be altered. A study by the Institution of Lighting Professionals [23] estimated that if the switching levels were reduced to 35 lx at dusk and 16 lx at dawn a saving of 50 hours per annum (approximately (1–2) %) could be achieved. Using this lower switch on/off lighting levels is not recommended for older lamp types such as low-pressure sodium lamps and mercury vapor lamps. Like discussed earlier, they need some time for the warm-up until their light output reach the operational value. Since mercury lamps have been phased out from the market by European Union regulation [24] and at the same time LED luminaires with new characteristics are ready to take over the market [2], photocells with switching routine of 35/16 lx are considered.

There is still potential for reducing the level or hours of operation of road lighting systems or switching off lighting whenever there is no need for lighting. For instance, during low traffic periods, every second luminaire can be turned off to save energy. However, this results in poor luminance uniformity. The dimming of luminaires may offer an acceptable alternative to switching off every second luminaire. Monitoring luminance level of road surface plays a key role in altering the road lighting outputs. Many factors can affect luminance levels of the road surface, such as road surface properties under varying weather conditions, and presence of car headlights on the road [12].

Weather conditions are also an important component in luminance of the road surface. When the road is covered with uniform snow, road surface luminance can substantially increase. Guo et al. (2007) [12] study indicated an increase of 150 % in road surface luminance in comparison with dry conditions.

Car headlights have also a significant effect on the road surface luminance. This was illustrated briefly by Guo et al. (2007) [12], in which car headlights increased the average road surface luminance value by 432 %.

The LED's capability to be frequently dimmed has made it possible to start developing control systems that react to the movements of individual road users. Such a system can fully satisfy road lighting regulation when a road user is present while providing a high level of dimming and energy saving at other times. In such cases, the maximum level of dimming is mainly dependent on acceptability to local inhabitants; for example, in rural areas, dimming down to (15–30) % of nominal light output is acceptable [13].

3.3. Car Headlights

Although considerable benefits can be gained by changing from conventional to LED road lighting, there is still another opportunity to reduce energy use and costs without affecting traffic safety. Aside from illumination by road lighting, drivers have car headlights. The combined effect of road lighting and car headlights is not complementary [25, 26, 27]. While road lighting illuminates road surface (horizontally), car headlights illuminate vertical objects on the road, and the combined effect of road lighting and car headlights reduce the contrast of objects on the road. Bozorg Chenani et al. studied this combined effect under different road lighting intensities with and without glare from an oncoming car in a stationary car [26]. The study used drivers' subjective grating of visibility performance and visibility level calculation as defined in the Adrian model [28]. The road had 100 W HPS light sources with the lighting class of M5 according to the classification system in CIE115:2010 [29]. The full road lighting had a voltage of 230 V and a luminous flux of 7252 lm. In addition to full road lighting, two other dimming levels, 71 % and 49 %, were studied with voltages of 210 and 190, respectively. They found that with only low beam headlights and in absence of glare from an oncoming car 49 % of road lighting intensity (corresponding to 4.5 lx) provided better visibility level than 100 % road lighting (corresponding to 8.3 lx) and 71 % of road lighting (corresponding to 5.9 lx) provided worst visibility level than the other two mentioned lighting levels. In addition, with low beam headlights and in presence of glare from an oncoming car there was a difference between different levels of road lighting but the effect was not significant [26].

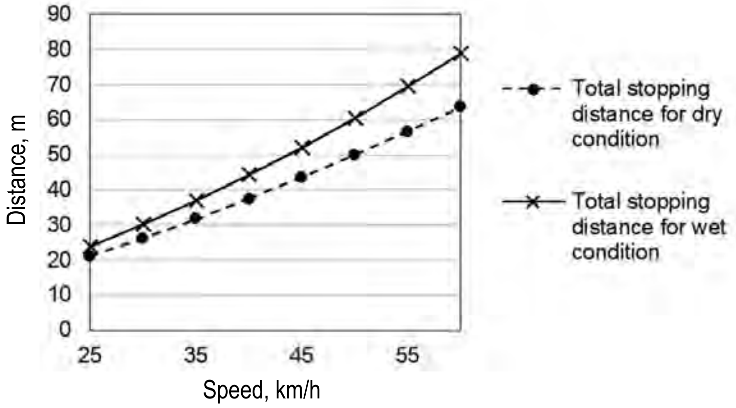

Fig. 2. Total stopping distance (TSD) for different speeds and weather conditions

Car headlights have been identified as being a potentially important parameter to dim road lighting. However, the range of car headlights are limited and driving speed can affect the effectiveness of car headlights (overdriving headlights). The assured clear distance ahead (ACDA) rule is known as maintaining speed low enough to enable the driver to stop within the range of vision and therefore, to avoid accidents with any obstacles that might appear in the car's path [30]. The main concern of ACDA rule is to find the maximum safe speed of travel, which is directly dependent on both the car and the driver as explained in Total Stopping Distance (TSD). TSD depends on the velocity of a car (m/s), perception and reaction time in sec, the coefficient of friction, and gravitational acceleration. In addition, the key human factors in TSD are perception and reaction time. These might vary due to environmental variables, drivers' experience, alertness, and physical condition of the driver [30]. American Association of State Highway and Transportation Officials [31] have appointed 2.5 seconds as the time required for most drivers to respond under most conditions and this 2.5 sec is used for perception and reaction time in road design. TSD for different speeds can indicate that car headlights can provide safe-visible distance up to 60 metres with speed up to 50 km/h (considering coefficient of 0.65 for dry condition and coefficient of 0.38 used for the wet condition for heavy truck, based on [31]). The findings of this theoretical knowledge are consistent with previous measurements studies. One criterion to examine the effectiveness of car headlights on visibility performance is detection distance with different speeds. Several studies indicate that low beam car headlights are enough while driving with low speed up to 50 km/h [32, 33, 27]. For instance, a study by Perel et al. focusing on driving with low beam car headlights alone provided enough visibility with speed up to 48 km/h [32]. In addition, it is known that on an unlit road and with only low beam car headlights, a young driver can only recognise an unexpected dark-clad pedestrian on average up to the distance of 15 to 45 meters from the headlights [33, 30].

Fig. 2 displays TSD for different speeds and weather conditions. Since car headlights have dominant effect in the area between 0 and 60 metres from car headlights [3], total stopping distances should be below 60 meters. Fig. 2 indicates that speed and road surface conditions can affect to different total stopping distance.

Also, driving with high speed can reduce the effect of car headlights (overdriving headlights) and increase the effectiveness of road lighting. Janoff et al. studied the detection distance of a small target with high speed (89 km/h) car in different road lighting intensities [34]. Their results indicated significant differences between full road lighting and other road lighting intensities. The best detection distance was achieved under full road lighting condition.

Therefore, there is a potential to reduce energy consumption by taking into account the combined effect of road lighting and car headlights in low-speed roads or when the car is approaching with low speed (lower than 50 km/h).

4. SUSTAINABILITY

4.1. Demand for Sustainable Outdoor Lighting

Due to the introduction of LEDs, the global lighting field is going through a transformation where

LEDs are replacing the conventional lighting technologies as new suppliers and organisations disrupt the industry [35]. The transition to LEDs has led the private actors to respond to the changing field and the demands regarding the environmental and technological properties of the new LED products by finding new international organisations such as Global Lighting Association [36] and Lighting Europe [37] and Zhaga [38]. This global change has also been supported by public and international organizations with the development of new international standards for testing LED products and by launching supporting programs and policies. The aim of these activities has been to further facilitate market transformation, international trade and diffusion of the new technology as LEDs' are expected to have a positive impact on sustainable development [39, 40].

However, from the different market segments especially the outdoor lighting segment is often a highly regulated domain of infrastructure of developed regions. In addition, investments in outdoor lighting are planned from a very long run perspective as investment calculations cover often even several decades [41]. In order to satisfy lighting network owners' and road users' expectations regarding functional lighting services, the outdoor lighting installations have to fulfil certain criteria as defined in international standards and recommendations of International Commission on Illumination (CIE), European Committee for Standardization (CEN) and American National Standards Institute and Illuminating Engineering Society (ANSI/IES). The standards for road lighting contain lighting requirements, including metrics for the luminance, illuminance, uniformity and disability glare produced by the luminaires.

But besides fulfilling the normative criteria, lighting installations are increasingly expected to be sustainable. This means that preference in technology selection should be put on those products, which minimize economic, environmental and social burdens and thereby determine sufficient conditions for adopting efficient lighting products. This kind of life cycle thinking entails assessing how products perform in terms of the sustainability aspects and what kind of trade-offs or dependencies, if any, exists between the different technologies and respective dimensions of sustainability [42,43]. However, sustainability assessment is still a developing framework where analysis can be conducted by combining different types of scientific assessment methods and tools [43]. For the purpose of outdoor lighting, Jägerbrand has developed a framework consisting of a set of sustainability indicators and measures for assessing especially LED luminaires' long-term sustainability from different perspectives [44]. Within the framework, the sustainability assessment is conducted by utilizing formalized indicators and methods in combination with qualitative approximations through several categories of environmental, economic and social sustainability. Moreover, the assessment of environmental and economic sustainability can be conducted with matured methods while the assessment of social impacts is still less uniform methodology [42, 45].

4.2. Assessments of Environmental and Economic Sustainability of Outdoor Lighting

The environmental and economic sustainability of different outdoor lighting technologies can be approached by comparing the performance of the alternative technologies during their different life cycle phases of environmental life cycle analysis (LCA) and life cycle costing (LCC) for financial cost accounting [46, 47, 48]. The diffusion of LEDs to road lighting has resulted in several comparative case studies with the aim to find out the environmental and economic sustainability of the products [49, 50, 51, 52, 53]. The main approach in case studies has been the comparison of the life cycle efficiencies of emerging LEDs and the dominating HPS lamps. Regarding the assessments, it has been proposed by Tetri et al. that the key parameters for comparisons are luminaire power, luminous efficacy, lamp and luminaire lifetime and pole spacing [2]. In addition, Tähkämö and Halonen suggest that assessments should use a kilometre of a lit road as the functional unit in the comparisons [49].

According to the recent results [49] and [2] the environmental impacts of HPS and LED luminaires are almost at the similar level where most of the impacts are created in the use phase of the luminaires: 96 % of HPS and 87 % in the case of LEDs. Thus, a specific feature of outdoor lighting is how different lighting products generate environmental impacts in the use phase, i.e. while the light is on. In addition to energy consumption, especially light pollution, which can be described as increased levels of artificial lighting in night-time environments [54] and lights illuminating unintended areas, is

Table 1. Comparison of Different Light Sources [2]

		Power (W)	Luminaire efficacy (lm/W)	Luminous flux (lm)	Annual burning hours (h/a)	Annual energy consumption (kWh/a)	Energy savings (%)
HPS		175	69	12000	4000	700	
LED	**Current**	120	100	12000	4000	480	31
		120	100	12000	2000[1]	240	66
	Future	60	200	12000	4000	240	66
		60	200	12000	2000[1]	120	83

[1] Burning hours reduced by 50 % with smart control

seen as a problem of different types of lighting technologies and luminaire designs [55]. Road lighting can cause light pollution described as sky glow and light trespass [56, 57] referring to the unintentionally lit areas [58] and increased brightness of the night sky [59].

Several steps have been taken to minimize these impacts. International Dark Sky Association and Illuminating Engineering Society of North America (IES) has developed tools for planning and selecting suitable lighting for outdoor purposes. The organisations have created a template for municipal lighting ordinances [60], which are aimed at combining outdoor lighting with lighting recommendations while simultaneously minimizing the negative use phase impacts [2]. Moreover, the template is supported by another tool for minimizing the negative use phase impacts of luminaires such as light pollution [61]. The rating system of IES is meant to help when selecting luminaires with adequate shielding for lighting installations.

Furthermore, the cost efficiency of HPS and LED luminaires has been assessed several times [2, 50, 53]. Often the purchase price of LED luminaires is much, even several times higher, than HPS luminaires [50, 53] creating an impression of higher total life-cycle costs. Besides the higher purchase price a major feature causing cost inefficiency for LEDs is the structure of the luminaire, which does not necessarily allow the changing of LED arrays at the end of their lifetime [50]. This increases LEDs maintenance costs during the long investment period as the whole luminaire has to be replaced during the maintenance period.

However, the studies using sensitivity and scenario analyses indicate that LED luminaires can be a cost-efficient choice over HPS luminaires [2, 50]. When acknowledging the development of the lighting industry and luminaire technology LEDs become a competitive alternative for HPS lamps [2]. The improved life cycle efficiency of LED luminaires has its roots in the global diffusion of LED science and technology [35] and the collaboration between the industry and academia. However, as the lighting technology has evolved the industry has attracted new entrants, which have adopted new operating models for building luminaires. These new ways of operating emphasize rapid prototyping and adaptation of automated manufacturing technologies such as robotics. As a consequence, enterprises have been able to quickly pilot and receive feedback from the early versions and improve products' quality for the next pilot. The increased number of competitive suppliers has lowered the purchase price of LED luminaires and is also a major explanatory factor for the products improved life cycle efficiency. On the other hand, the life cycle results are also subject to competition and local market structures indicating sensitiveness of the results.

LED luminaires have still further potential for efficiency gains and the luminaires can be optimized in respect of electricity consumption, luminous efficacy, and modularity and operation time. These advancements will make LEDs more efficient alternative than HPS technology in financial terms.

5. FUTURE OF ROAD LIGHTING

LEDs are a radical innovation and as they are evolving rapidly, they will be the dominating lighting technology. U.S. DoE has estimated that by 2020 the luminous efficacy of a LED luminaire could reach almost 200 lm/W [22]. Package luminous efficacy would be 220 lm/W and overall luminaire efficiency 89 %. Luminaire efficiency consists of thermal efficiency (93 %), driver efficiency (93 %), optical efficiency (94 %) and a correction factor for operating with reduced current (1.09). When compared to the state-of-art of discharge lamp luminaires' luminous efficacy (~60 lm/W), the luminaire luminous efficacy may be more than tripled in the future. If we use the suggested functional unit, kilometre of a lit road, we have to consider also luminaire's luminous intensity distribution, total luminous flux, pole height, pole spacing and other features as well. However, LED luminaires compete well with conventional discharge lamp luminaires. The luminous intensity distribution of a LED luminaire is enabled with external optics, usually with the lens, and thus the light can be directed to the area chosen even more effectively than with discharge lamp luminaires. Discharge lamp luminaires use reflectors to direct the light.

Benefits of LEDs over HPS luminaires can be summarized by 1) Higher luminous efficacy, 2) Higher lamp life, 3) Instant start with maximum luminous flux and no delay in re-ignition, 4) Luminous efficacy does not decrease in dimming, and 5) Dimming has no effect on lamp life [62]. In fact, reduced junction temperature in dimming use can increase LED's lifetime.

Table 1 shows that the optimized LED luminaire may result in an 83 % reduction in annual energy consumption compared to the HPS luminaire, whereas the current LED luminaire resulted in a 31 % reduction in energy consumption.

The future of road lighting systems is in intelligent lighting. Accordingly, CIE has developed a standard for intelligent road lighting that covers external parameters such as traffic density, remaining daylight level, road constructions, accidents and weather circumstances [29]. The development of the standard was supported by installing 20000 intelligent road lights across Europe (E-Street project [14]). As a result, an annual energy saving potential 38 TW·h was estimated by retrofitting old installations with intelligent road lighting. This represents approximately 64 % of the annual energy consumption of road lighting. The reason for the large-scale pilot of intelligent road lighting was based on the understanding that only low demand of light level is needed when there is very little traffic on the road. There has been a growing number of researchers in recent years that indicate that drivers do not require high lighting level when the traffic density is high because drivers' attention is on the back of the front car and in the range of car headlights [12, 25, 13]. Therefore, intelligent road lighting can be used not only in no or low traffic but also in high traffic, because of the illumination provided by car headlights. This also does not have an adverse effect on traffic safety.

LEDs and intelligent control technologies enable the change of outdoor lighting system in a way that the transition promotes sustainable development. LED luminaires improve sustainability of lighting especially due to the enhanced life cycle efficiency of the products. Moreover, the sustainability will be amplified by the emerging intelligent control technologies, which allow the supply of optimized lighting services based on the real-time demand of the users. However, we are still lacking knowledge of social impacts of road lighting, such as melatonin suppression. It is possible that in the future not only the light level is recommended, but also the correlated colour temperature (CCT). With LEDs, the CCT can be adjusted in the manufacturing process.

6. CONCLUSION

Today's energy and costs problems are accelerating the development of new technologies in road lighting systems. This paper has given an account of and the reasons for the future widespread use of LEDs and control technologies in road lighting. Some of the main benefits of using LEDs are long lamp life, high luminous efficacy and fast dimming. Therefore, the lighting control system can be adjusted in real-time based on real-time demand. Currently, several control systems are being practised which lead to saving energy. The control systems are mainly based on the ambient light, the amount of traffic and weather conditions. In periods when the traffic is low or when snow covers the road, the light output level can be reduced. Illumination of car headlights also has a great influence on the visibility of targets on the road.

The advancement of road lighting and control technology is going to change the concept of road lighting. The use of LEDs and intelligent control technology lead towards more sustainable lighting. Road lighting will be more efficient in economic and environmental terms and even in social terms. At the same time, the safety of drivers and other road users is on the same level or better than with conventional lighting solutions.

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