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LEDs Benefits and Challenges in Road Lighting

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ABSTRACT

Street lighting is one of the sectors where off-grid energy systems are used, and in the past decade interest in these systems has increased due to recent developments occurred both in LED and PV technology. An objective of this report is to provide information about LEDs benefits and challenges in road lighting, which will assist the engineers and researchers to develop the LEDs with the standards used for road lighting and its impact on drivers, pedestrians and environment. It also discusses the basis of quantitative recommendations for road lighting; the background to current guidance, the need to revise standards to respond to developments in science and technology.

Keywords: Road Lighting; Luminescence; LEDs; Electricity consumption; Energy Efficient.

I. INTRODUCTION

1.1 Luminescence:

Luminescence is nothing but the cold emission of radiation. It is the process in which the radiations are incident on material and get absorbed by the material and re-emit radiation of higher wavelength. In this process the wavelength emitted from the material is not the characteristic of incident radiation but of the luminescent material. The lamp emitted from it could be in the visible range, ultra-violet or in infra-red region [1].

The solid sample that further satisfies the luminescence phenomena are called as phosphors. Luminescence is alsodivided into two main types' viz. fluorescence and phosphorescence. The below flow-chart gives details of types of luminescence depends on time period.

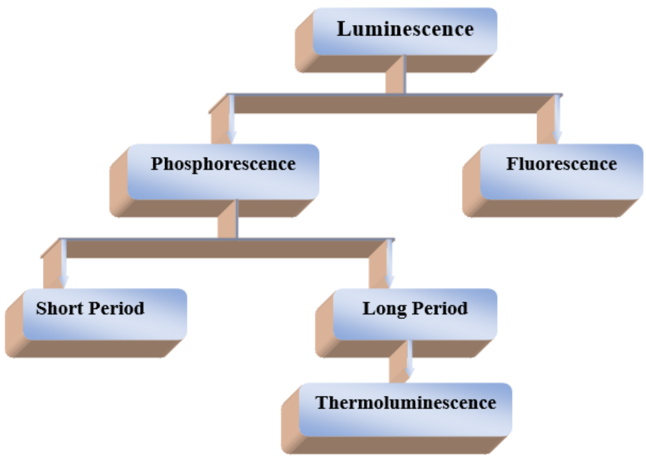

Fig 1: Types of Luminescence basis on time taken for emission.

According to figure 1, phosphorescence phenomena is divided into two parts viz. Short period which has time period less than 10^{-4} sec and other one is long period which has time period greater than 10^{-4} sec called as thermoluminescene[1].

Depending on the each source of energy and what the generate for luminescence is there are several types of Luminescence like[2] ***Bioluminescence, Chemiluminescence, Cathodoluminescence (CL), Electroluminescence (EL), Mechanoluminescence (ML), Sonoluminescence (SL), Radioluminescence (RL), Thermoluminescence (TL), Photoluminescence (PL), Ionoluminescence, Lyoluminescence (LL).***

1.1.1 Photoluminescence:

This type of luminescence is most commonly used in road safety and exit marking and it is called as persistent and long lasting luminescence. Photoluminescence has very large application area from whitening substances in washing powder to plasma screen for large displays. This is special type of luminescence which emission continuing for minutes and hours. The emission of lamp is by excitation electromagnetic photons/radiations.

This phenomenon can be classified into two types' viz. intrinsic photoluminescence and extrinsic photoluminescence[2]:

a) Intrinsic Photoluminescence:

As the name indicates the luminescence comes from inner side of crystals or pure materials. It is also divided into three more types,

Cross Luminescence: In this type of luminescence, an electron in the valance band recombines with hole created in outermost core band. This kind of luminescence is usually observed in alkali, alkaline-earth halides and double halides[1].

Exciton Luminescence: There are two types of excitons, Wannier exciton and Frankel exciton. The Wannier exciton is composed of an electron in the conduction band and a hole in the valence band bound together by the Coulomb interaction and is found primarily in IIIb–Vb and IIb–VIb inorganic semiconductors. The Frenkel exciton exists when the expanse of the electron and hole wavefunctions is smaller than the lattice constant and can be found in organic molecular crystals such as anthracene, inorganic complex salts such as tungstates and vanadates, and in uranyl salts. It should be noted that exciton is nothing but the bound electron-hole pair in which an excited electron is interacting with a hole. As the exciton moves through the crystal, it bring several energy and the electron and hole recombine to generate luminescence[3].

Band-to-band Luminescence: This type of luminescence found in the very pure materials at comparatively high temperature. It is also transformed into exciton luminescence at low temperature. This type of luminescence is found due to recombination of electrons in the conduction band with the holes in the valance band forming band to band transition. Few examples of this type of luminescent materials are Si, Ge and some IIIb–Vb compounds such as GaAs[2,3].

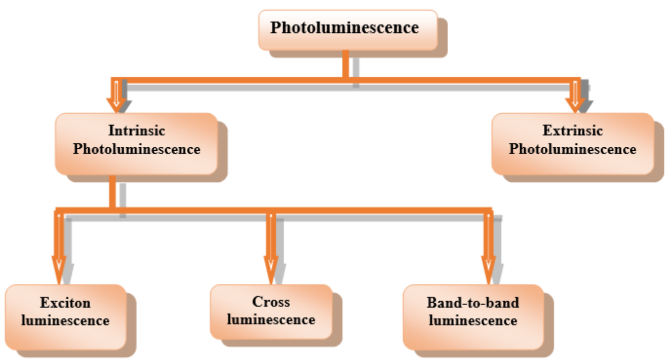

Fig 2: Flowchart : Types of photouminescence

b) Extrinsic Photoluminescence:

Extrinsic luminescence are the luminescence occurred by intentionally added impurities or defects into a phosphor and in ionic crystals and semiconductors. This luminescence may be localized or un-localized. It is localized when excitation and emission process of the luminescence are constrained within a localized luminescent center. Conversely it is un-localized when the free electrons in the conduction band and free holes in the valence band of the host lattice also contribute in the luminescence emissions[3].

Luminescence is the simply different process in the incandescence observed in the ordinary lamp bulb filament. In this phenomena, the energy in the form of electric current is directly supplied to the metal ion of the wire which creates vibration in it and hence it heat up. This wire glow white hot like in incandescent lamp filament. Characteristic of this lamp is come with great deal with heat. The electrical energy converted into radiation energy with great efficiency of 80% but only 10% of radiation can produce lamp in the visible region remaining radiations is produced in infrared region or in the form of heat. The radiation emitted from the wires or from any other object can non-sensitive to the feature of the object[2,3].

Above mentioned processes has its own advantages and significance in the field of science and technology. The present review is for discuss how lamp device systems are improved for eco-friendly lighting device from hazardous lamps for human health. For knowing this need to discuss about lighting devices till date.

In the modern era of LEDs are more preferable lighting devices because of its efficiency and its eco-friendly nature. These devices are mercury free, energy saving and safe for humans as well as environment. But still in India and many more countries LFL and CFL, LFL are also used as lighting devices which contain mercury and mercury is well documented as a hazardous material worldwide. But these lamps are budget friendly and easily available in the developing countries so the people in developing countries still really on these types of lamps. Here are some examples of mercury based lamps which is also budget friendly and consumes less power than incandescent lamps.

- Linear fluorescent, U-tube, and Circline lamps used for wide-ranging illumination purposes. They are extensively used in commercial buildings, schools, industrialized amenities, and hospitals.
- Bug zappers contain a fluorescent lamp that emanates ultraviolet lamp, attracting avoidable insects.
- Tanning lamps use a phosphor composition that emanates primarily UV-lamp, type A (non-visible lamp that can cause injure to the skin), with a small amount of UV-lamp, type B.
- Black lamps use a phosphor composition that renovates the short-wave UV within the tube to long-wave UV rather than to visible lamp. They are often used in forensic analysis.
- Germicidal lamps do not use phosphor powder and their tubes are made of fused quartz that is transparent to short-wave UV lamp. The ultraviolet lamp emission kills germs and ionizes oxygen to ozone. These lamps are repeatedly used for sterilization of air or water.
- High output fluorescent lamps (HO) are used in warehouses, industrialized amenities, and luggage compartment areas where bright lighting device is necessary. High output lamps are also used for outdoor lighting devices because of their less preliminary temperature, and as grow lamps. They gathering the same way as fluorescent lamps, but the bulbs are designed for much higher current arcs. The lamp emitted is much brighter than that of conformist fluorescent lamps. Nonetheless, they are less energy-efficient because they necessitate a superior electrical current.

- Cold-cathode lamps are small in diameter, fluorescent tubes that are used for backlighting in liquid crystal displays (LCDs) on a large variety of electronic components, counting computers, flat screen TVs, cameras, camcorders, cash registers, digital projectors, copiers, and fax machines. They are also used for backlighting device panels and entertainment systems in automobiles. Cold-cathode fluorescent lamps function at a much higher voltage than conventional fluorescent lamps, which eliminates the need for heating the electrodes and increases the effectiveness of the lamp 10 to 30 percent. They can be made of various colors, have high brightness, and long life.
- Compact fluorescent lamps (CFL) use the same basic technology as linear fluorescent lamps, but are folded or coil in order to estimate the physical size of an incandescent bulb. Screw-based CFLs typically use "quality" phosphors for good color, come with vital ballast, and can be installed in nearly any table lamp or lighting fixture that allow an incandescent bulb. Pin-based CFLs do not employ vital ballasts and are designed to be used in fixtures that have separate ballast. Both screw-based and pin-based CFLs are used in commercial buildings. Residential use of these types of bulbs is growing because of their energy efficiency and long life.
- High intensity discharge (HID) is the term frequently used for several types of lamps, including metal halide, high pressure sodium, and mercury vapor lamps. HID lamps function similar to fluorescent lamps. An arc is established between two electrodes in agas-filled tube, causing a metallic vapor to generate radiant energy. HID lamps do not need phosphor powder, however, because of an amalgamation of factors shifts most of the energy formed to the visible range. In addition, the electrodes are much closer together than in most fluorescent lamps. Also, under operating circumstances the total gas pressure in the lamp is relatively high. This generates enormously high temperatures in the tube, causing the metallic elements and other chemicals in the lamp to vaporize and generate visible radiant energy. HID lamps have very long life. Some emit far more lumens per fixture than typical fluorescent lamps. Like fluorescent lamps, HID sources operate from ballasts exclusively designed for the lamps' type and wattage being used. In addition, HID lamps require a warm-up period to achieve full lamp output. Even a provisional loss of power can cause the system to "re-strike" and have to warm up again a process that can take several minutes. The names of the HID lamps (i.e., metal halide, high pressure sodium, and mercury vapor) refer to the elements that are added to the gases that are usually xenon or argon and mercury in the arc stream. Each element type causes the lamp to have fairly diverse.

II. Importance of LEDs in road lighting

Driving is a mechanism where drivers cognitive, psychomotor and visual-perceptual functions are involved in a continuously altering environment. Many factors are responsible for road accidents. Human-related errors are responsible for most road injuries, but many of the researchers have provided the evidence that drivers' ability to avoid collisions is inhibited under dim lighting conditions. Road accidents were found to be 3. 5 times higher at night than during day time[4–6]. A comprehensive analysis of statistical data from 20 European Union (EU) showed that the majority of nighttime fatalities (58. 5%) in the EU occur in conditions of complete darkness (either the street lights are unlit or there are no street lights in place), whereas the remaining 41.5% corresponds to nighttime fatalities with the presence of lit street lights[7]. So researchers studied the impact of road lighting extensively. The International Commission on Illumination evaluated the effect of road lighting on accidents by analyzing 62 studies from 15 countries and based on before-and-after studies it was concluded that the installation of road lighting reduces the number of night time accidents by 30%[8].

The common method of road lighting uses fixed pole mounted lighting system to provide illuminance (illuminance is defined as the density of light flux falling on a surface) on and around the roadway. These illuminances illuminate potential hazards that might not be able to be seen with headlights of conventional vehicles improving the driving safety and reducing crashes at night time. Whereas roadway delineator patterns help the drivers to identify the roadway edge locations, information about curves and lane position, do not provide illumination which can make other objects visible. Visibility is the common criterion in road safety in relation to road lighting system, because the accidents mostly occur in darkness. The relative rate of occurrence of accidents can be reducing by pavement luminance produced by the lighting. Luminance of the road is related to safety as it gives the visibility to driver on the road. So there is the need to improve the visibility. Several lighting technologies are used for road lighting and other outdoor lighting needs, such as for parks, public areas, or parking lots. But the conventional lighting technologies include sodium vapor (high/low pressure sodium), mercury vapor, metal halide, fluorescent tube lights, compact fluorescent lamps and incandescent lights, have many disadvantages and worst effect on environment. The IEA also estimates that electricity demand will continue to surge and is expected to grow by as much as 67% by 2035; this demand will be primarily met with fossil fuels. Carbon emissions from the power sector will rise from 13.0 GT in 2011 to 15.2 GT in 2035. Despite the growth, the IEA still predicts that nearly one billion people will continue to "live in the dark" by 2035, as they will not have access to modern energy services. .Where as the United Nations stresses the urgency of action to reverse climate change, as the longer society waits to implement measures against climate change, the more costly and difficult it will be to reverse or limit its effects.

Apart from road accidents, the demand of electricity and impact on climate are also the necessary measures to ensure the sustainable future, for which there is a necessity to adopt energy efficiency on large scale. The latest road lighting systems are supported by LED technology. The LED lighting is the cost-effective, easy to implement, and high-impact solutions to scale back carbon emissions. It is a step in the right direction to achieve greener and safer transport, de-carbonize and beautify cities and urban places, and promote sustainable and inclusive growth in rural areas.

In the new era of lighting system after drawbacks of CFLs, LEDs are widely used. LEDs are highly efficient, less power consuming comparable to CFLs and these are recyclable and toxic free because it has no contents of mercury[9,10].

Enhancement of the luminous intensity in last few years sets a benchmark. Fig. 3 shows the historical improvement in the history of lighting efficiency from Edison's first light bulb to today's modern era WLED[11].

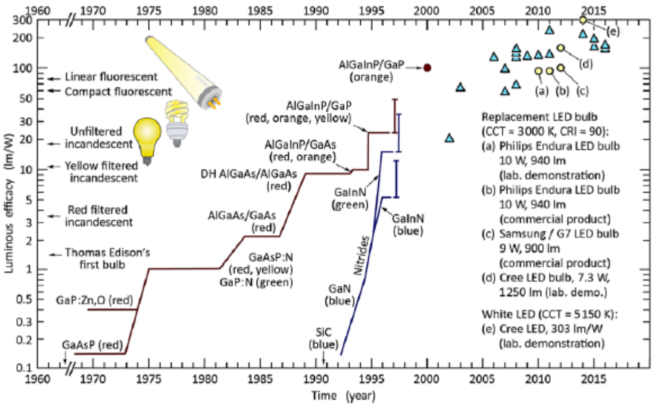

Fig. 3: Development of luminous efficacy of visible-spectrum LEDs and luminous efficacy of conventional light sources (incandescent and fluorescent sources)

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This figure illustrates that the beginning of LED technology from 1960. If we consider the revolution of technology from 1960 to 2000 is constant then the enhancement in efficiency of LED is doubled in every 4 years[11]. This figure also reveals that performance of LEDs as compared to red and yellow incandescent lamps is improved by large margin.

With high efficiency and less power consumption technology LEDs also has 10 times more lifetime as judge against to ordinary incandescent lamps. Due to this advancement LEDs have bright future in the lighting industry. Fig. 8 shows some advance applications of WLED in different fields.

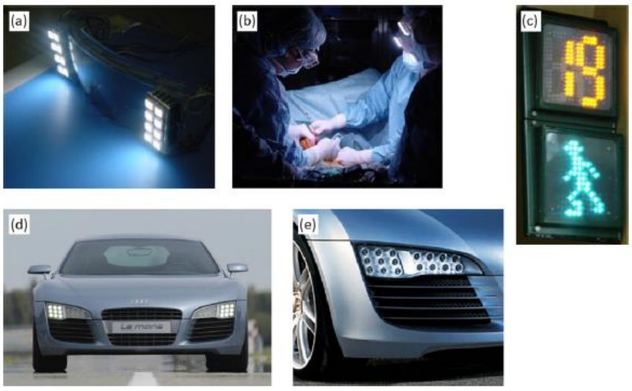

Fig. 4: (a) First goggle with integrated white LEDs used for (b) illumination during medical surgery. (c) Pedestrian sign indicating number of seconds left to cross street. (d) & (e) First automotive daytime running lights based on LEDs (Reprinted with permission from ref. [11] Copyright © 2017, John Wiley and sons.).

Fig. 4(a) & 7(b) shows the LED incorporated on medical glasses worn by the surgeons during surgery. While surgery surgeons need to focus and LEDs are light weight and its high efficiency unidirectional technology helps to the doctors during operation. Fig. 4(c) shows the LEDs are used as a display for traffic signals. In fig. 4(d) & fig. 8(e) LED based automotive headlights first used in Audi car in 2004.

An objective of this report is to provide information about LEDs benefits and challenges in road lighting, which will assist the engineers and researchers to develop the LEDs with the standards used for road lighting and its impact on drivers, pedestrians and environment. It also discusses the basis of quantitative recommendations for road lighting; the background to current guidance, the need to revise standards to respond to developments in science and technology.

III. Lighting for drivers and pedestrians

The ability of drivers to spot hazards and avoid collisions is hampered by poor road lighting. Although vehicle traffic is much lower at night than during the day, more than half of all fatalities are due to traffic accidents that occurred after dark. When lighting is installed on the road, the number of road accidents caused by drivers generally decreases on average by about 30 %, under the most favorable conditions by up to three times[13,14]. Lighting significantly improves the visibility of the road, increases the range of vision and makes obstacles more visible to road users earlier and more easily. It should be possible to see obstacles and other road users from a distance appropriate to the mobility dynamics of road users, so that behavior (driving maneuvers, pedestrian avoidance) can be adapted to avoid collisions[13].

The most important role of street and safety lighting is to prevent road accidents and also provide the necessary light for clear vision at night. It helps to improve the safety of drivers, riders, and pedestrians. Moreover, the effectiveness of lighting in preventing accidents depends on its illuminance. Brighter the lighting, better is the visibility to prevent accidents. Street and safety lights improve visibility by reducing the glare impacts of headlights of approaching vehicles; they also improve the visibility of objects and markings on the roadway beyond the range of vehicle headlights[15]. In addition, other factors, namely the need for energy-efficient lighting systems, increased demand for intelligent solutions in street lighting systems, and increasing penetration of LED lights and luminaires in street and safety lighting drive the deployment of street and safety lighting systems. Europe is predicted to carry the important size of the world wide street and safety lighting market within next few years thanks to stringent government regulations pertaining to lighting efficiency followed by many European countries such as Germany, the UK, France, and Italy, while the market in APAC is expected to grow at the highest rate in the coming years[15].

The basis of current road lighting recommendations

The Commission Internationale de l'Eclairage (CIE) describes two main purposes of road lighting: (1) to allow all road users, including operators of motor vehicles, motor cycles, pedal cycles and animal drawn vehicles to proceed safely; and (2) to allow pedestrians to see hazards, orientate themselves, recognise other pedestrians and give them a sense of security[16].

To achieve these purposes, guidelines and standards for road lighting are provided. They are:

Appropriate luminance or illuminance level

Color (or other characteristics derived from the spectral power distribution(SPD).

Spatial distribution of light.

These standards are written and reviewed by committees representing a cross-section of the Industry manufacturers, designers, installers and researchers.

3.1 Early Standards:

In 1927, British standard was suggested by Waldram[17], identified 8 classes of lighting, defined by minimum mounting height and maximum space : height ratio[17]. While minimum illuminances were also defined for each of the eight classes ranging from 0.1lux (0.01 foot candles) to 21.5 lux (2.0 foot candles) at a test point. Revised standards after experimental installation was suggested in 1928 by Waldram. Other than performance such as illuminance or luminance many other standards related to lighting system characteristics such as between post spacing according to road width were prescribed. These was because availability of limited range of lamp type. After 1980 computers were used for lighting design. So in 1985 British standards based on CIE recommendations replaced the 1974 code of practice[18].

Table 1 Example is from British Standards Code of Practice 1004:1974

Light distribution cost	Height (m)	Minimum Lower hemisphere Flux (lm)	Design Space (m)										
			Effective road width (m)										
			11	12	13	14	15	16	17	18	20	22	24
Cut off	10	12,000	33	33	33	31	29	27	26	24	22		
	12	20,000			40	40	40	40	37	35	32	29	26
Semi cut off	10	12,000					44	44	42	40	36		
	12	20,000							53	53	52	47	43

3.2 Standard for driving

Road lighting recommendations given by the Illuminating Engineering Society of North America (IESNA) is based on the work of Box[19]. Box examined the relationship between illuminance and frequency (or motor way) crashes on 203 miles of road. In his work first he considered presence and absence of load lighting and found day/night crash rate ratios for lit and unlit roads were 1.43 and 2.37 respectively, which he used to calculate an expected crash rate. He concluded that installing road lighting on freeways reduced nighttime crashes by an average of 40%. Second he considered light level , where he concluded that roads with the lower range of illuminances (0.3 to 0.6 horizontal foot candles (HFC) or 3.2 lux or 6.4 lux) had a lower night/day crash ratio than roads with higher range illuminance (0.8 to 1.1 horizontal foot candles or 1.3 lux or 1.5 lux; 8.6 lux to 11.8 lux and 14 lux to 16.1 lux). On the above data he concluded that 0.5 HFC (5.4 lux) is better for freeways, whereas higher lighting level increases the crash rate ratio. Additional lighting can create additional glare and impacts the drivers adaptation level[19].

Despite these limitations, the 0.5foot candle illuminance determined by Box has been carried into luminance criterion. The luminance of any point on a road surface may be a function of the illuminance on and therefore the reflection properties of the pavement material. Therefore this method requires knowledge of road surface properties and the geometry between the light source and the observation position relative to a point on the surface[20,21]. But this luminance method is also limited in adverse weather and wet road surface conditions due to changes of surface reflection[22,23].

STV (small target visibility) approach was implemented in the US standard IESNA RP-8 in 2000[24]. This approach is based on the detection of a small object in the roadway. The IESNA document allowed the use of 3 methods for calculating light levels on roadways they are illuminance, luminance and STV. Local agencies can choose any one of the above methods for lighting design.

3.3 Standards for pedestrians

Main purpose of road lighting is to enable pedestrians and cyclists to orientate themselves and detect vehicular and other hazards, and to discourage crime against people and property[16]. CIE guidance states that the road lighting should enable pedestrians to discern obstacles or other hazards in their path and remember of the movements of other pedestrians, friendly or otherwise, who could also be in close proximity. In 1930, British Minister of transport recommended that lighting on traffic routes should be sufficiently good for drivers to proceed safely without the use of headlights[25]. The 1992 British Standard recommended three lighting classes for subsidiary roads, these having horizontal illuminances of 3.5 lux, 6.0 lux and 10 lux, with the selection defined by a narrative description of the typical application. In 1995, CIE recommended six lighting classes, with average horizontal illuminances starting from 1.5 lux to 20lux. In 2003, EN 13201-2:2003 also recommended six lighting classes but with a narrower range of illuminance and this range was retained in later updates to standards[25].

3.4 The need of new standards

The standards given by different agencies for driving as well as for pedestrians do not appear to be founded in robust empirical evidence. Evidences should show that the assumed benefits of lighting do exist (i.e. improved visibility, improved safety, improved feeling of safety), and second to point out how these benefits could be suffering from changes in context and changes in lighting.

Due to developments in the technology of road lighting and the technology of research, and developments in our understanding of vision and the side-effects of road lighting there is need to form new standards.

IV. Development in the technology of road lighting

Waldram and the online archive of Simon Cornwell described the development in the technology of road lightning[26]. In 1405, order was passed by Aldermen of the city of London that a lighted lantern should be hung outside every house along the road. In 1461 candles of standard specification were used. In 1807 gas lamps were used first in London. Arc lamps were used in public places in Paris in the year 1878 and in 1879 in Cleveland. From 1880, Arc lighting and Incandescent lighting were introduced for road lighting in London. Introduction of Discharge lamps in 1930s is described as the 3rd milestone in street lighting by Waldram et.al. The disadvantage of Discharge lamp was that they gave light of unfamiliar color, which has strange and unflattering effects on personal appearance. In 1932, first time Low pressure sodium lamps were installed, followed by High pressure mercury vapor in 1933, Fluorescent in 1946 and High pressure sodium in 1966. But all these lamps were having three limitations. They are, first they give yellowish orange color light with low color rendering index and limited options for SPD (Spectral Power Distribution),second they are large in size with limited opportunity for optical control and third they have switching-on cycles which can require several minutes to reach full output.

All these limitations are removed in solid state lighting. Solid state lighting is a type of lighting that use semiconductor light emitting diodes (LEDs), organic LEDs or polymer LEDs. The second decade of the twenty-first century has become the period when light-emitting diodes (LEDs) are used for road lighting as well as outdoor- indoor areas because of following advantages. First they have very fine optical control due to the small size of individual units, second limitless control over SPD, if sufficient primaries are used, third it can be switched on and off instantaneously and last very important consumes less energy. Due to small size of LEDs it can be used as lane markers and can provide a better solution than overhead road lighting in some situations[27,28]. This is likely to reduce sky glow and energy consumption.

Visual conditions in road lighting should fall within the mesopic region, where both rods and cones provide significant responses, so road lighting recommendations are given using photopic quantities. The introduction of LEDs which, compared with sodium and mercury lamps, significantly enhance the chance to vary and tune SPD.

V. Side-effects of road lighting

It was concluded that the aim of lighting guidance should be to make sure that the right quantity and quality of lighting is employed, where and when it's of benefit and also referred to the management and use of light for administering a drug[29]. He said light has both benefits (positives) and unwanted side-effects (negatives) so needed to control the dosage of the light so as to provide the maximum benefit minimizing the negatives.

One reason to suspect that light levels are on the high side and will be reduced is that they have tended to rise with time. For example, the maximum Changes in technology have moved towards lamps of greater efficacy and light levels may have increased, because there was an ability to do so, not because there was evidence of a benefit to be gained from higher light levels[30].

In 1972, Waldram discussed the 'sky haze' due to street lighting[26].The discussion of sky glow has continued, showing, for instance, that the use of LEDs of high CCT (6500K) increases scattered light and hence sky glow compared with conventional sources of lower CCT[31]. Too much light or an inappropriate quality of light might also lead to wasteful energy consumption[32], to light trespass on property[33] and to unwanted impact on the natural environment[34]. While there are strong lobbies to reduce the impacts of these externalities, by using lower light levels, restricted spectral tuning or optical control, recommendations still need to meet the intended benefits for road users, e.g. a pedestrian's ability to detect a visit hazard or a driver's ability to detect a pedestrian on the carriageway. For this, we would like robust evidence of how such benefits are affected by changes in lighting and this often is not evident in existing standards.

One impact of lighting side-effects is that there may be a need to consider additional or alternative recommendations. The average illuminances and uniformity of current standards may no longer be sufficient and future standards may need to include maximum light levels, limitations for SPD and spatial distribution and exposure doses[30].

VI. Lighting parameters deciding quality road lighting:[35,36]

- **Lumen output (Lm):** Amount of light emitted by the light source.
- **Lamp wattage (W):** Amount of electricity required by the lamp to emit the lumen output.
- **Luminous efficacy (Lm/W):** Luminous or lumen efficacy measures the efficacy of the light source – an LED in the case of LED lighting system, and lamps in case of conventional technologies. It measures how much light is being emitted by the light source per unit of power and is expressed in lumen per watt of electricity used.
- **System wattage (W):** Amount of electricity required by the system to emit the lumen output.
- **System efficacy (Lm/W):** Luminaires include ballasts, drivers, heat management systems, optics, all of which can diminish the original luminous efficacy of the light source. Since the road surface is being lit up by the luminaire as a whole, system efficacy is a better metric to use than luminous efficacy when making comparisons.
- **Watts per square meter (W/m2):** The amount of power required for each lighting appliance to illuminate a road surface to the required light level. For road lighting, this is the most appropriate way to measure the efficiency of a light source, though lumen efficacy or lumen output are often considered easier to measure.
- **Lifetime (hours):** Lifetime of LEDs is measured differently than conventional lighting technologies, which reach end of life at the point when they stop producing light entirely. However, LEDs typically do not stop producing light completely, but depreciate or dim over time to a point where the lumen output is insufficient to meet the required light levels. For LEDs, industry defines lifetime as the point when the LEDs lumen output reaches 70% of the original.
- **Color Rendering Index (CRI):** An index used to measure an artificial light's ability to reproduce the colors of an object, relative to the natural light source (the sun) with CRI of 100. Higher CRI means better visibility.

VII. Performance Comparison of LED's and conventional technologies [37,38]

Table 1 : Comparison of LED's and conventional technologies

	LED	High Pressure Sodium Vapour(HPSV)	High Pressure Mercury Vapor
Distance between poles	30m	30m	30m
Number of poles	33	33	33
Investments($)	$$$	$$	$
Lamp Wattage	70W	150W	250W
System Wattage	70W	180W	300W
Luminous Efficacy	90-130Lm/W (rapidly improving)	100Lm/W	60Lm/W
System Efficacy	90-130Lm/W (rapidly improving)	80Lm/W	48Lm/W
Watts per square meter(W/m^2)	0.33	0.86	1.42
Life Time	50k hours	12k hours	5k hours

Annual Energy Consumption	$1,532	$3,938	$6,563
Hazardous Substances	No	Yes	Yes
Color Rendering Index(CRI)	>70	25	<60

The important differences between the three technologies as shown in above table 1 are as follows:

• W/m² and energy consumption costs: Being providing directional light, LEDs are efficient in lighting up the specific surfaces like roads and thus bringing down the W/m² values. Compare to conventional lighting sources, LEDs have the lowest annual energy consumption cost.

• Lifetime: LEDs even have the longest lifetime, and despite higher initial investment, LEDs tend to be the foremost cost-effective lighting option within the end of the day . This is thanks to other cost savings incurred during its operational lifetime including maintenance, repair, replacement, and disposal costs.

• Hazardous substances: LED systems are safer for the environment as they are doing not contain hazardous substances (e.g., mercury) as defined in international norms and also last longer, thus converting them to trash fewer times.

VIII. Benefits of LED road lighting[39,40]

Significant benefits offered by LED road lighting which are not possible with conventional lighting are as follows:

Technological benefits:

Evolution of technology from analog to digital have made all the electrical appliances such as radio, television and camera to switch to digital in past few decades. Same way LEDs are the next stage evolution in lighting technology and giving lighting solutions from analog to digital technology. The technical benefits provided by LEDs include:

1. **High lumen efficacy**:

Currently, commercially available luminaires from quality suppliers typically have efficacy levels of 90-100 lm/W. Lumen efficacy: It is the luminous flux divided by the electrical power consumption of a light source. The terms energy efficiency and electricity consumption are related to luminous efficacy; as luminous efficacy is inversely proportional to electric power for producing luminous flux required for illumination. A comparison between the luminous efficacies of top-performing LED and conventional lighting products is shown in Table 2[41].

2. **Directionality and Reduced Light Pollution:**

LEDs are "directional" light sources, which suggests they emit light during a specific direction, unlike incandescent and CFL, which emit light and warmth altogether in all directions[42]. Due to this property of LEDs light wastage is reduce and also prevent unwanted dispersion of light to residences, nearby areas, and the night sky, thereby reducing light pollution. The high lumen efficacy combined with directionality makes LEDs suitable for several energy-saving lighting applications.

3. **Long lifespan**:

Laboratory testing and experience indicate that well-produced LED systems last 50,000 hours or more, depending on usage. Thus having 5000 to 15000 hour lifetime compared to most conventional lamps[42].

4. **Superior quality of light:**

LED lighting features a high CRI, which along side its white light, offers enhanced already dark visibility, making the roads brighter and safer. Some initial research shows that LED road lamps achieve greater light penetration through fog[43].

5. **Extended controllability**:

LED lighting may be a digital technology making dimming and similar control functions possible and straightforward. LED users can make precise adjustments to brightness, monitor fixture operation from a centralized location, and optimize energy efficiency by altering light output as needed. In addition, while conventional lighting technologies have shorter useful lives once they are dimmed, the effect on LEDs is that the opposite: LED life is extended when dimmed[44].

IX. Durability

LEDs are highly immune to vibration and other mechanical stress making them suitable for road lighting, especially on bridges, elevated highways, and where there could also be risk of vandalism.

Table 2: Comparison between luminous efficacies of (top) best in class LED products and (bottom) conventional lighting products.

2016 Top Performing LED Products*	**Luminous Efficacy (lm/W)**
LED A19 Lamp (Dimmable, 2700 K)	100
LED PAR38 Lamp (3000 K)	80
LED T8 Tube (4000 K)	149
LED 6” Downlight (3000 K)	86
LED Troffer 2' x 4' (3500 K)	129
LED High/Low-Bay Fixture (4000 K)	136
LED Street Light (5000 K)	118
Conventional Lighting Products	**Luminous Efficacy (lm/W)**
Incandescent A19	15
Halogen A19	20
CFL A19 Replacement	70
CFL (Dimmable) A19 Replacement	70
Linear Fluorescent System+	108
HID (High-Watt) System+	115
HID (Low-Watt) System+	104

Economic Benefits:

LED lighting is more economical compare to conventional lighting, Its direct and Indirect benefits include:

1. **Lower lifetime cost:**
During its for much longer lifetime of 50,000 hours (compared to 15,000 hours or less for an alternate conventional technology), the entire cost of ownership (TCO) of an LED road lighting system is lower by 50% or more. The TCO of a road lighting system includes energy, lamp replacement, and labor and maintenance costs.

2. **Income generation**:
Effective road lighting helps extend light hours in cities also as rural areas. This promotes tourism; longer business hours for businesses like food vendors, shops, entertainment centers; and other evening activities leading to jobs and income generation

3. **Savings along the energy sector value chain:**
By being more efficient, LED road lighting reduces the quantity of energy needed from the grid and frees up capacity during peak hours. This allows governments to meet growing energy needs from existing infrastructure and avoid or postpone investments such as for power plants, transmission lines, and distribution networks.

Social Benefits:

1. **Road safety:**

LED road lighting provides better quality light, which increases visibility for both drivers and pedestrians improving road safety conditions, especially in poorly lit areas and highly populated cities in developing countries[45].

2. **Energy savings, environmental benefits**:
Road lighting is the major part of overall energy consumption by lighting. Besides the energy savings, a shift to LED technology results in an equivalent drop in GHG emissions, about 0.6375 Kg per kWh saved. In addition, LEDs have other "green" benefits: They do not emit infrared radiation or harmful ultraviolet (UV) rays and do not contain mercury, a toxic metal found in several conventional lighting technologies.

3. **Better citizen security, livable cities**:
LEDs add to a city's aesthetic appeal vibe, helps improve city branding, and cultivates civic pride. In a 2012 survey by The Climate Group, 80% of those surveyed reported that LED street lighting made them feel safer for reasons such as brighter lighting and better facial recognition.

X. Challenges to LED Road Lighting Adoption

LED road lighting being a technologically superior product, several challenges need to be addressed before it is used for the rural and urban development.
These challenges include:

1) Energy saving but insufficient illumination: Energy saving is that the energy saved under an equivalent average illumination, which isn't just the typical illumination on the ground! The light intensity of the space features a excellent forecast for the vehicles coming within the distance, to stop traffic accidents from happening! But the LED street lights installed are sacrificing illumination to realize energy saving.

2) Heat dissipation of LED Street Lamp: When street lamps are used outdoors, they need to be waterproof and dustproof, therefore the lamps must be sealed. After sealing, the temperature of water vapor in the lamps must exceed 100 degrees under extreme weather conditions. The LED street lamps will still add such a hot environment if the warmth dissipation isn't done well. Lamps and lanterns are extremely susceptible to breakage or severe light decay. The heat dissipation of high-power LED street lamps is still not completely solved, and the cost of follow-up maintenance is bound to increase.

3) The penetrability of LED Lamp: In rainy days , foggy days , the LED light is not strong to penetrate through the fog and rain.

4) Outdoor easy to move mosquito repellent incense: Because mosquitoes are particularly fond of the LED wavelengths of light, there are moths to catch fire, which will affect their luminous efficiency.

5) Lack of globally accepted international standards: There is still no consensus regarding what standards to follow for LED road lighting systems. It is a complex, new product and not many know how to see through tricks played by low-quality suppliers, and set a tender that would keep out poor quality products.

XI. CONCLUSION

There is a need for new standards responsible for road lighting. The effective standards will be the one which is related to the benefits for road users so that they can travel safely , feel safe and minimize the risk of road collisions. All in all LEDs are the strong candidates for replacing conventional light sources as they enhance the vision quality in road lighting in addition to energy saving.

Road lighting using LEDs is cost-effective, easy to implement, and high-impact solutions to reduce carbon emissions. EE lighting is a step in the right direction to achieve greener and safer transport, de-carbonize and beautify cities and urban places, and promote sustainable and inclusive growth in rural areas.

This report provide the information about LEDs benefits and challenges in road lighting, which will assist the engineers and researchers to develop the LEDs with the standards used for road lighting and its impact on drivers, pedestrians and environment. It also discusses the basis of quantitative recommendations for road lighting; the background to current guidance, the need to revise standards to respond to developments in science and technology.

XII. REFERENCES

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