# Road lighting: A review of available technologies and appropriate systems for different situations

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## Abstract

This review focuses on the criteria a lighting system should satisfy with regard to road safety issues and then lists the light source technologies that meet the needs of different situations. Important factors to consider when choosing technologies are the visual needs (whether peripheral vision is important), colour rendering, light efficacy and lifetime of the system.

## Introduction

Traditionally, for outdoor spaces a wide range of light source technologies have been used, with sodium discharges (high and low pressure) being the most frequent for efficacy reasons (highest efficacies in the market reaching 200 lm/watt for the low pressure version) followed by mercury lamps (high pressure mercury and low pressure mercury fluorescent lamps). However, as the issue of outdoor lighting in the road environment is closely connected to the safety of people (pedestrians and drivers), more specific proposals are made based on special visual requirements.

Before considering the actual light sources, there are certain criteria that the whole *luminaire* (device or system which creates artificial light via electric lamp) must satisfy for road and general outdoor lighting:

- The luminaire or lighting system must be designed in such a way that it has protection from weather and vandalism (considering such factors as height of pole, materials used and protection masks). Generally speaking, the higher up a lamp is fixed, the bigger the area of illumination, but the greater the requirement for lamps with greater lumen (measure of visible light emitted from a source) outputs.
- The illumination must be uniform, avoiding shadows and dark spots. This generally means that the distance between poles and the number of lamps (it is better to have many lamps than a few brighter ones) must be carefully considered. The advantage of using more lamps is that failure of some will still provide some illumination until replacement takes place.
- The luminaire chosen must also reduce glare and light pollution. Various groups of people (such as astronomers) already push the demand for light pollution reduction so cut-off luminaires such as the one shown in Figure 1 (see images at the end of the article) must be preferred.
- The issue of adaptation (and glare) is of particular importance when it comes to tunnels where drivers move from very bright environments to low light levels and vice versa in a very short time (Figures 2 and 3). This contrast causes adaptation difficulties for the drivers so specially built entrances and exits must be designed in order to prevent such abrupt changes.

## Recommended light source technologies

With the above in mind, a number of proposals can be put forward for the type of lamps or light source technologies to be used in different situations in the road environment. It is important to match the features of each technology to the appropriate conditions.

- Off-axis visual detection is quite important as obstacles and pedestrians would be off the central vision axis. Research shows that illumination of the roads and streets with light sources that aid peripheral vision would prove beneficial [1-2]. The fact that the eye functions in mesopic conditions further enhances this reasoning. Therefore, light sources that stimulate the peripheral vision (rod stimulation) are important. This means that lamps with emissions **rich in blue light (cool white light sources)** should be preferred [3-4]. Mesopic vision describes the transition region from rod vision (scotopic) to cone vision (photopic), where signals from both rods and cones contribute to the visual response. This intermediate situation corresponding to dusk conditions is especially important for street lighting systems. Under photopic conditions, the sensitivity of the human eye peaks at 555 nm. As the luminance decreases, the peak of the sensitivity shifts towards lower wavelengths. The peak sensitivity under scotopic conditions is at 507 nm. These data are known as the spectral luminous efficiency functions or the $V(\lambda)$ curves. There is not an equivalent standard for the mesopic region yet and there will be developments in this area soon. The fact that rods are more sensitive to low light environments, that the scotopic vision shifts to shorter wavelengths and that rod concentration increases in the periphery of the retina, mean that rods and peripheral vision are more sensitive to blue light.
- A **high colour rendering index** is desirable as this would enhance colour contrast. This enhances perception of brightness and gives road users accurate information on events.
- As road lighting systems operate throughout the night, they must be cost- effective. This means that **high efficacies** and **long lifetimes** are required.

Table 1 shows the available technologies and some of their key characteristics, such as colour temperature ranges and colour rendering indexes. Some technologies have been excluded due to the fact they are either obsolete (simple incandescent, high pressure mercury, neon) or still in the developmental stages (organic LEDs).

**Table 1. Characteristics of various light source technologies [3–4]**

| | HA | FL | LPS | HPS | MH | CMH | LED |
|---|---|---|---|---|---|---|---|
| Efficacy lm/W | 30 | <120 | 200 | 50-150 | 100 | <95 | <80 |
| Power/W | <2000 | 5-165 | <180 | 35-1000 | <2000 | 20-250 | 0.1-7 |
| Colour Temperature /K | <3500 | wide | 1700 | <3500 | wide | 3000-4200 | wide |
| Colour Rendering Index (CRI) | 100 | >90 | 0 | 20-85 | >90 | >90 | >90 |
| Lifetime/k hours | 2-5 | 10-30* | 20 | 10-30 | 10-20 | 10-20 | >50 |

HA = halogen incandescent FL = all types of mercury fluorescent LPS = low pressure sodium HPS = high pressure sodium MH = metal halide lamps CMH = ceramic metal halides LED = light emitting diodes

Based on the above points of colour rendering, lifetime, more emissions in the blue region and high fluxes, the lighting technologies suggested are

- **Cool white metal halide lamps**
- **Cool white fluorescent lamps** (inductive lamps would offer longer lifetimes)
- **Cool white LED systems** could also be a good solution as they have long lifetimes and the appropriate colour temperature can be selected. However, there are still some issues to consider such as their cost, light fluxes and efficacies. It is a matter of time though before they can fulfil all the criteria and find a place in outdoor/road lighting. An important advantage of LEDs is that, due to thermal management issues, they perform better in cold environments, which is usually the case with outdoor spaces during the night.

Figure 4 shows photographs of these cool white technologies.

Solar LED lamp systems for road lighting can also be found in the market but such systems so far have found widespread use only in applications where not much light is required (such as in gardens or lighting of footpaths) as they are easily installed and maintained; they also provide a cheaper alternative to wired lamps. High pressure xenon lamps could offer the high light fluxes, the good colour rendering properties and the colour temperatures required for a range of outdoor spaces; however, this technology is not recommended because the efficacy and lifetime is lower than the above technologies.

### Situations where sodium lamps should be retained

Although new light technologies which facilitate peripheral vision have made sodium lamps replaceable, there are a few cases where they should be retained.

- Sodium lamps should be used in open roads or tunnels where there are no pedestrians or significant traffic or known obstacles causing safety concerns (Figures 2 and 3).
- They should be used in places where fog and dust are frequent. This is due to the higher penetration of longer wavelengths (yellow compared to blue). Scattering increases with shorter wavelengths so in such environments the longer wavelength yellow light is desired.

## Closing statement

It is clear that different situations have different requirements. For each case there will be different technologies that offer particular advantages. Lighting systems should be chosen to satisfy the relevant criteria regarding reliable performance, uniformity and appropriate visual stimulation to enhance road safety.

## Terms and definitions

(sources: the websites of GE Lighting and Philips Lighting; an extended index can be found in [4])

**Average rated lifetime** As average rated lifetime we define the time duration beyond which, from an initially large number of lamps under the same construction and under controlled conditions, only 50% still function.

**Colour Rendering Index (CRI)** An international system used to rate a lamp's ability to render object colours. The higher the CRI (based upon a 0-100 scale) the richer colours generally appear. CRI ratings of various lamps may be compared, but a numerical comparison is only valid if the lamps are close in colour temperature.

**Colour Temperature** Measured in Kelvin, CCT represents the temperature an incandescent object (like a filament) must reach to mimic the colour of the lamp. Yellowish-white ('warm') sources, like incandescent lamps, have lower colour temperatures in the 2700K-3000K range; white and bluish-white ('cool') sources have higher colour temperatures.

**Correlated Colour Temperature (CCT)** A term used for discharge lamps, where no hot filament is involved, to indicate that the light appears 'as if' the discharge lamp is operating at a given colour temperature. CCT generally measures the 'warmth' or 'coolness' of light source appearance using Kelvin(K) temperature scale.

**Cool White** A lamp with a colour temperature of 5000 K to 6500K.

**Efficacy** A measurement of how effective the light source is in converting electrical energy to lumens of visible light. Expressed in lumens-per-watt this measure gives more weight to the green region of the spectrum and less weight to the blue and red region where the eye is not as sensitive.

**Efficiency** The efficiency of a light source is simply the fraction of electrical energy converted to light, i.e. watts of visible light produced for each watt of electrical power with no concern about the wavelength where the energy is being radiated. For example, a 100 watt incandescent lamp converts less than 10% of the electrical energy into light; discharge lamps convert more than 25% into light. The efficiency of a luminaire or fixture is the percentage of the lamp lumens that actually comes out of the fixture.

**Eye Sensitivity** The curve depicting the sensitivity of the human eye as a function of wavelength (or colour). The peak of human eye sensitivity is in the yellow-green region of the spectrum. The normal curve refers to photopic vision or the response of the cones.

**Fovea, Foveal Vision** A small region of the retina corresponding to what an observer is looking straight at. This region is populated almost entirely with cones, while the peripheral region has increasing numbers of rods. Cones have a sensitivity peaking in the green and corresponding to the eye response curve.

**Kelvin** A unit of temperature starting from absolute zero. Zero Celsius (or Centigrade) is 273K.

**Photopic** The vision for which the cones in the eye are responsible; typically at high brightness and in the foveal or central region.

**Rods** Retinal receptors that respond to low levels of luminance but cannot distinguish hues. Not present in the centre of the fovea region.

**Figure 1. Cut-off luminaire**

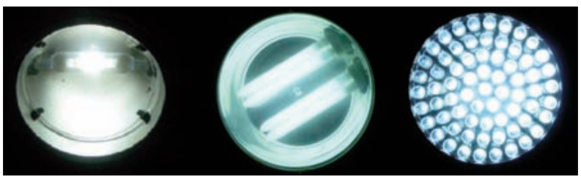

**Figure 4. Cool white light emitting technologies – metal halide (left), fluorescent lamp (middle) and LED (right)**

**Scotopic** The vision where the rods of the retina are exclusively responsible for seeing (very low luminance conditions and more sensitive to blue emissions).

**Warm White** This refers to a colour temperature of < 3500K, providing a yellowish-white light.

## References


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**Figures 2 and 3. The luminance contrast can lead to glare (top) or areas to appear darker (bottom) than they really are. The photos illustrate this in a tunnel.**

**Sergeant Michael Musumeci (second from left) and members of the Project RAPTAR team**