PREMIUM LIGHT PRO

This project is funded by the European Union

LED Street Lighting

Procurement & Design

Guidelines

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1. Introduction

Modern LED lighting solutions are advancing rapidly and can deliver significant energy saving potentials. Increasing efficacy, optimized luminaire design and flexible lighting control enable enhanced performance at lower cost for different lighting and traffic conditions. While implementation of LED in the outdoor lighting market is proceeding, broad market penetration has not yet been achieved. Furthermore, there is still large potential for improving local and national policies supporting the implementation of LED lighting systems.

The initiative PremiumLight-Pro supports the development of such policies by:

- the development of green procurement and design guidelines for both private and public service sector LED installations, including both outdoor and indoor lighting;
- providing education, training, and information services for planners, architects, installers, and consultants;
- disseminating best practice case studies implemented on the basis of such policies.

The guidelines provided with this document focus on green procurement and design for street lighting systems and are primarily intended for procurement professionals and decision makers at federal, local and municipal levels who are in charge of commissioning new or renovated street lighting installations. Furthermore the guidelines may be useful for street lighting designers and planners and contracting companies, as well as energy specialists and consultants.

The recommendations for using these guidelines strongly depend on the specific background and purpose of the reader. Experts already familiar with the basics for LED street lighting for example may directly check the specific PremiumLight-Pro recommendations for procurement criteria in chapter 4. Experts less familiar with the basics may first of all browse through chapters 2 and 3, which cover the basic information relevant for understanding the procurement criteria, including the important quality and efficiency aspects for street lighting and the standard EN 13201. Chapter 5 finally showcases some of the selected best practice examples for LED street lighting.

2. Quality, safety and efficiency aspects for street lighting

2.1 Introduction

Efficient high quality street lighting solutions based on LED technology need to be based on sound quality, efficiency and safety criteria. The following chapters provide an overview of the most essential criteria and explain specific aspects of LED technology.

2.1.1 Quality criteria

Quality criteria describe essential aspects such as luminance, light colour, colour rendering, light distribution, flicker, glare and others.

2.1.1.1 Luminance

Several metrics are used to quantify the amount of light provided by a lighting system and perceived by the human eye.

The **luminous flux** (measured in lumens, or lm) is the total amount of radiation emitted by a given light source that is visible for the human eye. As the sensitivity of the human eye varies for different wavelengths (e. g. higher sensitivity for green light compared to red or blue light), the luminous flux is adjusted accordingly.

The **luminous intensity** (measured in candela, or cd, with 1 cd = 1 lm/square radian) represents the spatial distribution of light measured as the luminous flux within a given solid angle from the light source. For street lighting, the spatial distribution must ensure that the road, street furniture and road users are adequately illuminated, while any upward lighting is often undesirable (see light pollution, below).

The **illuminance** (measured in lux, or lx, with 1 lux = 1 lm/m²) represents the total amount of light reaching a particular illuminated surface area. Minimum illuminance criteria are specified for the different road classes except for motorways (see section 2.2.1). Typical minimum illuminance requirements for roads in areas with complex traffic situations (for example, areas with viewing distances of less than 60 m, or when road users also include cyclists or pedestrians) range from 7.5 to 50 lx (see section 3.1.1 for details). Recommendations for standard illuminance and luminance requirements are specified in EN 13201 (see chapter 2.2 below).

Finally, the **luminance** (measured in cd/m²) represents the brightness of lit surfaces or objects as perceived by the human eye. Minimum luminance requirements for medium to high speed traffic routes range from 0.3 to 2 cd/m². [EN 13201-2] Thus, the luminance normally falls within the so-called "mesopic range" of human vision (which ranges from 0.001 to 3 cd/m²) which combines both colour (photopic) vision and low-light (scotopic) vision. In this range, human reaction time to new stimuli is determined by both contrasts in brightness and contrasts in colour. Thus, both the luminance of the illuminated area and the colour rendering of the light source (see 2.1.1.3, below) are important for human perception and consequently for traffic safety. Minimum luminance requirements are specified for road classes covering medium- to high speed motorways (see section 2.2.1).

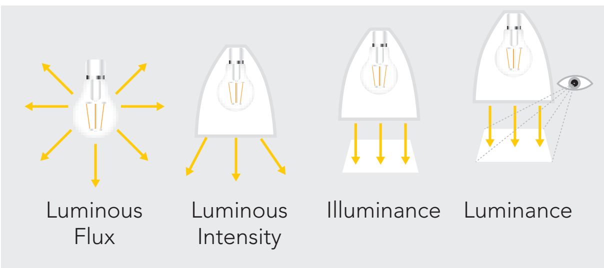

Figure 1 *Different definitions of light quantity*

2.1.1.2 Glare

Glare is an unpleasant visual effect caused by unfavourable distribution of luminosity or high contrasts, forcing the eye to adjust rapidly [see also EN 12665-1]. Two types of glare effects are typically distinguished: Disability glare, which is caused by the scattering of light in the eye which reduces contrast sensitivity, and discomfort glare, which triggers a subjective sensation of discomfort.

While susceptibility to disability glare may vary for different individuals (in particular, the effects will increase with age), it can be calculated objectively. In a particular illuminated environment, the human eye will be able to detect differences in luminance down to a certain threshold. This threshold can be compared for a situation in the same environment when a source of glare is added. By comparing these thresholds, the threshold increment can be derived.

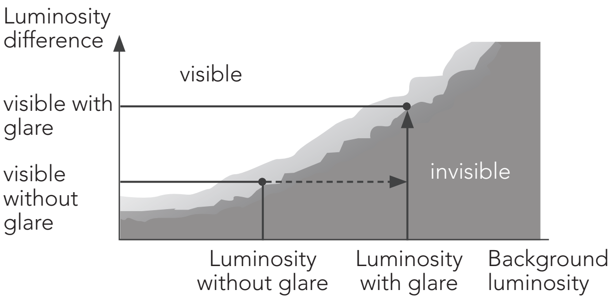

Figure 2 *Visibility with and without glare*

Discomfort glare, on the other hand, is a subjective phenomenon and there is no consensus for how it should be rated – although the 9-point DeBoer scale (ranging from "1" for "unbearable" to "9" for "unnoticeable") is the most widely used in the field of automotive and public lighting.

Since disability glare reduces the ability to perceive small contrasts, it can impair important visual tasks in traffic such as detecting critical objects, controlling headlights, and evaluating critical encounters, making glare a potential danger for road users. Glare triggered by LED road lights is influenced by the following factors:

- The ratio between the illuminance from the glare source at the observer's eye and the background luminance.
- The angle between the glare source and the observer's line of sight.

LED light sources can provide very high luminance levels which may cause glare. For this reason, LED lamps are commonly equipped with diffusors to reduce this luminance. Street lighting systems should be designed in a way to avoid significant differences in luminance levels at the light source and on lit areas. Furthermore, continuous variation of lighting levels can cause eyestrain and should be avoided, in particular on long roads. Higher luminance levels facilitate the adaptation of the eye to headlights of other vehicles. For further discussion about the design of street lighting systems, see Chapter 3.

Different classifications have been introduced for discomfort and disability glare to classify different shield levels. Shield classes for disability glare range from level G1 to G6 and are further specified in EN 13201-2 (see table 1). Shield classes for discomfort glare are specified as D1 to D6 (see table).

Table 1 *Glare classes for disability glare [EN13201-2 and VEJ]*

Shield class	Maximum luminous intensity in cd/klm			Total shielding
	at 70°	at 80°	at 90°	
G1		200	50	No requirements
G2		150	30	No requirements
G3		100	20	No requirements
G4	500	100	10	above 95° to be zero
G5	350	100	10	above 95° to be zero
G6	350	100	0	above 90° to be zero

Table 2 *Classification for discomfort glare [VEJ]*

Glare value classes	
D0	not specified
D1	7000
D2	5500
D3	4000
D4	2000
D5	1000
D6	500

2.1.1.3 Light colour – colour temperature and chromaticity

Light sources often emit a large range of different wavelengths while usually being perceived as having a single colour. This apparent colour is referred to as the so called "colour temperature" of the light source. The colour temperature corresponds to a reference colour of an ideal "black body radiator" being heated to a specific temperature (measured in Kelvin). The sun, for instance, has a colour temperature of 5780 K when observed at noon and closely approximates a black body radiator.

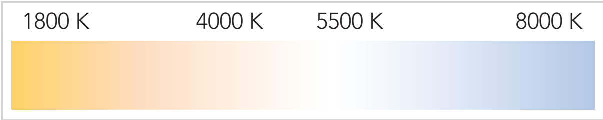

Figure 3 *Colour Temperature*

The light colour used for street lighting typically varies between yellowish, neutral and bluish white corresponding to colour temperatures between 2500 and 5000 Kelvin. Different European regions have shown different preferences concerning light colours both for indoor and outdoor lighting. For example "cold white light" (bluish) is more popular in southern countries while in mid and northern European countries there is some preference for warm white light. Thus in mid and northern European countries light with high colour temperature may be less well accepted by residents.

LED lighting, in contrast to various old lighting technologies, offers the opportunity to adjust or select colour temperatures flexibly for various applications. However, it should be considered that the colour temperature of the light source has an effect on the energy efficiency of the lighting system and may cause physiological effects for human beings and animals. Cold white light with a high colour temperature supports a higher energy efficiency level of the lighting system. A high level of blue light in cold white light sources on the other hand may also cause health and safety issues which have to be considered (2.1.1.6). Research has shown that white light supports the perception of the human eye more effectively than yellowish light, and therefore appears brighter.. Consequently white light (e.g. 4000 K) may typically be preferred for complex road situations with different types of road users involved (e.g. cars, cyclists, pedestrians). In contrast, lower, warmer colour temperatures may be preferred for domestic areas.

Overall the selection of the colour temperature is an important aspect of street lighting design. LED lighting is able to provide the whole spectrum of colour temperatures and thus offers the basis for careful selection of the appropriate light colour for different needs and applications.

Besides colour temperature, the so called chromaticity – the concrete coordinates of a light colour in the spectrum of colours – may be used to specify the uniformity of the colour of a specific lamp type. These colour coordinates may also be used to describe variation of the light colour over time. Differences of the light colour in a batch of lamps or over a certain period of time are indicated by so called MacAdam ellipses. The colour consistency of a specific lamp or luminaire type can be indicated by the size of the MacAdam ellipse. Requirements concerning colour consistency for a batch of lamps and over time also may be specified for procurement. Minimum requirements for products sold on the EU market are currently specified in the relevant EU legislation. The current minimum requirement according to the eco-design legislation is a five-step MacAdam ellipse.

2.1.1.4 Colour rendering

Light sources of the same colour temperature may perform quite differently in terms of representing the colours of lit areas and objects. Thus the specific colour rendering does not depend on the colour temperature of a light source but on the spectral wavelengths emitted by the source. Light sources providing a full spectrum of wavelengths can represent all colour variations of lit objects in a very natural way. Light sources emitting only selected colours only support the representation of these specific colours.

An important practical example of this is facial recognition by pedestrians – which also requires the ability to perceive colour contrast. Studies have shown that people need to be able to recognize faces at a distance of 4 m to feel secure (see the P, HS, and SC lighting classes in section 2.2.2 that include facial recognition aspects). [LRT]

The colour rendering capability of light sources is quantified under lab conditions by means of eight specified standard colours. Colour rendering is represented by the colour rendering index (CRI, maximum index value is 100). Lighting systems with colour rendering of 80 or better are suitable for good facial recognition. [LRT] Concerning LED lighting, the specific rendering for red light is also relevant. This so-called R9 value is typically not included in the classical CRI but the extended index covering 14 standard colours. For LED lighting the standard CRI and the R9-value should be considered in combination. Table 3 shows typical colour rendering levels for different technologies used in street lighting. LED-luminaires typically provide a colour rendering index value better of 80 or higher. For streets with a simple pattern of utilisation a colour rendering of Ra 70 is often sufficient. For more complex usage and lighting situations Ra above 80 may be desirable.

Overall both the light colour (colour temperature) and the colour rendering of a light source are relevant for the visibility and perception of objects in the environment.

Table 3 *Colour rendering index for street lighting systems [BG]*

Lamp type	CRI
High pressure mercury	40–60
Metal halide	70–95
Low pressure sodium	monochromatic
High pressure sodium	20
LED	80+

2.1.1.5 Colour maintenance

Colour maintenance is an issue of particular concern for LED lighting, as aging LED modules may change their colour temperature and colour coordinates. Problems with colour maintenance can be caused by degradation of the material used for the encapsulation or lenses of LEDs, contamination, or other types of system degradation. Causes currently under investigation may be high operating temperatures, higher operating currents, and discoloration of optical materials due to blue or ultraviolet radiation.

So far, only a few LED package manufacturers offer warranties for colour maintenance, and no standard procedures for predicting colour maintenance are available. [ENG]

Colour deviation over time can be specified and assessed by the colour coordinates and MacAdam ellipses.

2.1.1.6 Light pollution

Artificial lighting can have detrimental effects on humans and animals and this includes the undesired outdoor spread of light, or light pollution. For humans, the effects range from excessive illumination of the night sky in and near cities to disruptions of the sleep cycle by badly positioned outdoor lighting in residential areas. Animals on the other hand use natural light sources as a navigational aid and thus may become confused or scared away by artificial illumination. Many animals perceive different ranges of wavelengths than humans.

Studies have shown that LED road light sources attract fewer insects than other technologies, with "warm white" LEDs (colour temperature of 3000 K) resulting in significantly lower numbers than with "cold white" LEDs (colour temperature of 6000 K). [SdN]

One way of reducing light pollution is to use luminaires which direct the light only on the areas to be illuminated. Directional light sources incorporating LEDs are especially suited for achieving optimised light distribution. Light emissions above the light source are generally not desired.

The light emitted upwards from the luminaire is quantified by the upward light output ratio (abbreviated as ULOR or RULO):

$$\textbf{ULOR} = \frac{\text{upward lumen output of luminaire}}{\text{total lamp lumen output}}$$

Depending on their vertical light distribution, luminaires are divided into four basic types [IIEC]:

- **Full cut-off** luminaires: a maximum of 10% of the total lumens of the lamp are emitted at an angle of 80° above the nadir, and 0% at angle of 90° above the nadir.
- **Cut-off** luminaires: a maximum of 10% of the total lumens of the lamp are emitted at an angle of 80° above the nadir, and 2.5% at angle of 90° above the nadir.
- **Semi-cut-off** luminaires: a maximum of 20% of the total lumen of the lamp can be perceived at an angle of 80° above the nadir, and 5% at angle of 90° above the nadir.
- **Non-cut-off** luminaires: emit light into all directions.

This traditional definition of cut-off is extended to six different luminous intensity classes in EN 13201-2, which also includes maximum values for an angle of 70° and above. See section 2.2.2 for further details on EN 13201-2.

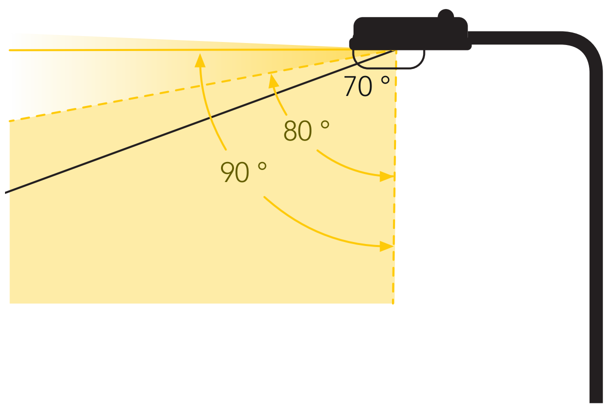

Figure 4 *Definition of cut off criteria*

Table 4 *Ingress Protection (IP) rating*

IP Code	First digit	Second digit
0	No Protection	No Protection
1	Protected against solid bodies greater than 50 mm	Protected against dripping water/condensation
2	Protected against solid bodies greater than 12 mm	Protected against rain water up to 15° from the vertical
3	Protected against solid bodies greater than 2.5 mm	Protected against rain water up to 60° from the vertical
4	Protected against solid bodies greater than 1 mm	Protected against water splashing in all directions
5	Protected against dust (no harmful deposits)	Protected against water jets from all directions
6	Fully protected against dust	Protected against wave-like water jets from all directions
7		Protected against immersion
8		Protected against the effects of prolonged immersion under water

[IIEC, 2015]

Further options for reducing light pollution include:

- **Reducing illuminance:** This measure has to be weighed against safety requirements for human road users. Smart lighting control can adjust illuminance to appropriate levels for specific times and situations (see Section 3.5) [JAE]. However, switching off or reducing lighting later at night (for example, between midnight and 5:30 am) is unlikely to provide much benefit for the local wildlife as for example bats and other nocturnal species are active in the early hours of the night when street lighting systems are still operating at maximum level [BAT].
- **Changing the spectrum:** The sensitivity of animals and birds to different light colours varies from species to species. Overall lighting technologies which emit a narrow "warm-white" spectrum of light – such as low-pressure sodium (LPS) lamps – appear to have lower ecological impact than other technologies. With LED technology colour temperature can be varied according to needs. However quality and safety requirements have to be met.

LED lighting technology can be used to create a more uniform level of illumination. High-intensity discharge (HID) lamps such as HPS (high pressure sodium) or MH (metal halide) lamps have higher peak levels of illumination directly below the luminaires but "dark refuges" between the luminaires.

2.1.2 Safety criteria

Luminaires for street lighting must be protected against foreign matter (both solid and liquid), mechanical impacts as well as voltage fluctuations in order to guarantee their continuous proper operation. For this purpose requirements on ingress protection, impact protection and voltage protection are typically specified.

2.1.2.1 Ingress Protection

The resistance of luminaires against foreign matter is indicated by the so-called Ingress Protection (IP) code, a two-digit number defined by the IEC 60529 standard. The first digit represents the resistance against solid matter, while the second rates its resistance against liquids (see table 4).

For street lighting, IP65 luminaires should be used to ensure sufficient resistance to dust, particulates and inclement weather. [IEA]

2.1.2.2 Mechanical Impact

The resistance of luminaires to mechanical impacts is indicated by their Mechanical Impact (IK) code, a number defined by the IEC 62262 standard:

Table 5 *Mechanical Impact (IK) rating*

IK rating	Impact strength in Joules
00	–
01	0.15
02	0.2
03	0.35
04	0.5
05	0.7
06	1
07	2
08	5
09	10
10	20

As outdoor luminaires may be hit by loose tree branches or other debris in strong winds or even may be subject to outright vandalism, a minimum of IK08 is recommended.

2.1.2.3 Voltage protection

Transient over-voltages (increases in voltage above the standard design voltage that last from microseconds to a few milliseconds) may cause damage to LED modules and control gear. Their resistance to such fluctuations is measured by the overvoltage protection rating.

While EN 61547 regulates minimum criteria for overvoltage protection for LED lighting, it specifies a mere 0.5 kV phase to neutral wire/earth – insufficient for more serious situations such as lightning strikes. Many street lighting projects mandate overvoltage protection up to 10 kV for this reason. [ZVEI2]

2.1.3 Efficiency criteria

Compared to most other technologies, LEDs reach very high energy efficiency levels (lumen per Watt of power).

Table 6 *Typical energy efficacy values for street lamp types [BG]*

Lamp type	Energy efficacy [lm/W]
High pressure mercury	60
Metal halide	120
High pressure sodium	150
LED	150

The total efficiency of LED lighting systems not only depends on the LED module efficacy, but also on the luminaire, the light control system and the overall lighting system design. For this reason, it is important to distinguish efficacy at LED module level, luminaire level and total system level.

The efficiency of the system as a whole among others is influenced by the spatial light distribution (luminous intensity) and the geometrical arrangement of the road and the lighting system (see sections 3.2 and 3.3 for more detailed aspects). To assess the energy efficiency at road system level the power density indicator (PDI) was developed as a suitable metric.

While the power density indicator provides useful information about the energy efficiency for a particular state of illumination in a street lighting system, illumination levels may change through the night and the year depending on lighting control systems implemented. Total energy efficiency and energy consumption over a year therefore is better expressed by the annual energy consumption indicator (AECI). Section 2.2.3 explains PDI and AECI in more detail.

2.1.4 Lifetime

In order to quantify the lifetime of LED modules, the IEC 62722-2-1 standard defines the following metrics:

The **average rated life Lx** specifies the time it takes until the average LED module provides less than x per cent of its initial lumen output. For instance, L80 50,000 h means that the lumen output of the module decreases by 20 % after 50,000 hours of operation.

The **rated life LxBy** indicates the percentage y of the LED modules will have the lumen output x after the period specified. Thus, L80B10, 50,000 h should be read as:

- After 50,000 hours of operation 10 % of the LEDs will have equal or less than 80 % of the original luminous flux.

The **time to abrupt failure Cz** describes the time after which z per cent of the LEDs have failed. Thus, C10 50,000 t = 35 °C should be read as:

- After a time of 50,000 hours and an ambient temperature of 35 °C 10 % of the installed LED luminaires with the same LED modules have experienced total failure.

Due to the long lifetime of LEDs and their comparably short development cycles, the rated lifetimes and failure values are statistical extrapolations and should be considered as such. Furthermore, the actual lifetime of a luminaire may depend on several factors. Total failure and the degradation of the luminous flux of a luminaire further depend on its electrical and thermal operating data, ambient temperature and other parameters. The planner must obtain all relevant data from the manufacturers in order to select a luminaire suitable for the intended application and create suitable maintenance plans based on this information [ZVEI, 2015]. LEDs generally have a lifetime of 100,000 hours or above. The lifetime of the luminaire control gear also needs to be taken into account which is usually expressed as a percentage chance of failing within a particular time period, such as "a failure rate of 0.2 % per 1,000 hours".

2.2 European Standard EN 13201

The primary goal of street lighting is to ensure safety on roads during dark periods. Good street lighting systems make it possible for road users to identify people, obstacles, and sources of danger nearby or directly on the road. This allows traffic participants to act accordingly, and help enable reduced severe accidents in the dark.

The quality criteria for street lighting are defined in the European standard EN 13201 "Street lighting" which covers the following topics:

- PD CEN/TR 13201-1:2014: Guidelines on selection of lighting classes
- EN 13201-2:2015: Performance requirements
- EN 13201-3:2015: Calculation of performance
- EN 13201-4:2015: Methods of measuring lighting performance
- EN 13201-5:2015: Energy performance indicators

2.2.1 Selection of lighting classes

PD CEN/TR 13201-1:2014 defines a parameter system for a detailed description of all typical lighting situations in road traffic. Using the European standard the lighting requirements can be determined according to the specific conditions of the roads. Various lighting parameters, such as the geometry of the traffic area, type of traffic use and environmental influences are used to identify lighting classes for which qualitative and quantitative lighting requirements are described.

PD CEN/TR 13201-1:2014 uses a selection procedure for determining lighting classes M1 to M6, C0 to C5, and P1 to P6. It does not give guidelines for the selection of lighting classes HS, SC and EV, which are available at national level for each country.

The selection criteria for each subclass (as designated by their digit) are based on the geometry of the road, its traffic usage, and its environment. The effective criteria (based on PD CEN/TR 13201-1:2014) include:

- Design speed or speed limit
- Travel speed (for lighting class P)
- Traffic volume
- Traffic composition
- Separation of carriageway
- Junction density
- Parked vehicles
- Ambient luminosity
- Facial recognition (for lighting class P)
- Navigational task

Certain parameters (in particular traffic volume, traffic composition and ambient luminosity) may change from season to season, or during different hours of the night. Thus road sections may be shifted to a different road class.

[PD CEN/TR 13201-1:2014; EN 13201-2:2003; EN 13201-2:2015]

2.2.2 Performance requirements, measurement and calculation methods

Part 2 of EN 13201 provides specifications for the different lighting classes which are defined by a set of photometric requirements depending on the needs and requirements of the specific road users and road types.

The lighting classes simplify the development and application of street lighting products and their maintenance in the member states. In order to broadly harmonize the requirements, the lighting classes were defined on the basis of the national standards of the member states and the CIE 115:2010 standards.

Part 2 introduces a number of additional metrics which are used to define minimum or maximum criteria for each subclass.

M class roads are routes for motorized traffic with medium to high driving speed. To fulfil the criteria of the standard, care must be taken to maintain a minimum average road surface luminance, a minimum uniformity of the luminance of the road surface (with separate minimum values given for dry and wet conditions), a minimum uniformity of luminance along the centres of the driving lanes, a maximum level of glare, as well as ensure that the illuminance outside the carriageway does not fall off too quickly.

C class roads represent conflict areas where motorized vehicles have to expect other road users (such as pedestrians or cyclists) or otherwise have to navigate complicated traffic situations, such as complex road intersections, roundabouts, queuing areas, and so forth. While lighting systems for C class roads still need to meet a minimum uniformity of the luminance of the road surface, most other criteria for M class roads are not applicable or impracticable (for instance, many conflict areas do not have a clear strip of land next to the carriageway suitable for calculating how quickly the illuminance falls off beyond the carriageway).

Instead, they are required to maintain an average horizontal illuminance on the road area. While C class roads – unlike M class roads – do not have mandatory criteria for minimizing glare, Annex C of EN 13201-2 provides informative criteria for this class.

P and HS class roads are intended for pedestrians and pedal cyclists on footways, cycle-ways, emergency lanes, and other road areas lying separately or along the carriageway of a traffic route, as well as residential roads, pedestrian streets, parking places, schoolyards and so forth. Criteria for P class roads include a minimum maintained average illuminance on the road area, and a maintained minimum illuminance on the road area. If facial recognition is important, additional criteria for vertical plane illuminance (at a point) and minimum semi-cylindrical illuminance (on a plane above a road area) must be adhered to. As an alternative to the P class, the HS class bases its criteria on the overall uniformity of road surface luminance as well as the average hemispherical luminance.

SC class roads are an additional class for pedestrian areas where facial recognition and feelings of safety are especially important. They require minimum levels of maintained semi-cylindrical illuminance.

EV class roads are an additional class for situations like interchange areas where vertical surfaces need to be perceived clearly.

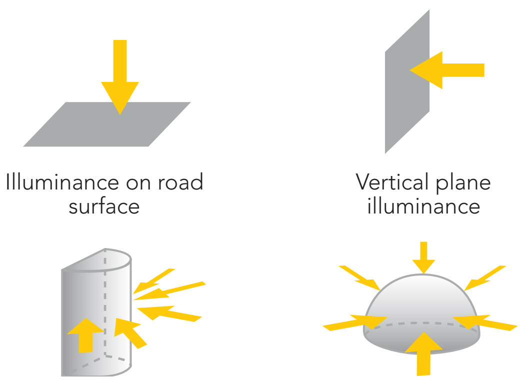

Figure 5 *Illuminance criteria types*

Additionally, the informative Annex A of EN 13201-2 introduces six different luminous intensity classes for the reduction of glare where the normal metric (threshold increment) cannot be calculated. Classes G*1, G*2, and G*3 correspond to the traditional "semi cut-off" and "cut-off" concepts, while G*4, G*5, and G*6 correspond to full cut-off. See section 2.1.1.4 for the definition of these terms.

EN 13201-3 describes the mathematical methods and procedures which should be used to calculate the lighting performance characteristics defined in EN 13201-2.

EN 13201-4 describes the methods that should be used for measuring lighting performance. There are four basic types of situations when measurements should take place:

- at the final testing phase measurements should be taken in order to verify compliance with standard requirements and/or design specifications.
- at pre-determined intervals during the street lighting lifetime in order to quantify lighting performance degradation and determine the need for maintenance.
- continuously or at pre-determined intervals in order to adjust the luminous flux of the luminaires, if the road uses adaptive street lighting (e.g. the luminance or illuminance is controlled in relation to traffic volume, time, weather, or other environmental factors).

2.2.3 Energy performance indicators

EN 13201-5 describes the two energy performance metrics power density indicator (PDI) D_P (measured in $W/(lx \cdot m^2)$) and the annual energy consumption indicator (AECI) D_E (measured in $(Wh)/m^2$) which already have been introduced in the previous chapter. These indicators should always be used together for the assessment of the energy performance of a particular lighting system.

The power density indicator defines how to calculate the energy performance of a particular street lighting installation and makes it possible to compare different setups and technologies for the same street lighting project (as different locations will have a different geometry and environmental conditions, PDI values can only be used to compare different setups for the same installation). The following information is needed in order to calculate the power density indicator for any given area:

- The **total system power** *P* of the lighting system (either the entire installation or a representative section), which includes both the operational power of all the individual lighting points (light sources and any associated devices gear) as well as of devices not part of the individual lighting points but necessary for their operation (such as centralized control systems and switches).
- The **maintained average horizontal illuminance** $\bar{E}$ (in [lx]) of each sub-area (as well as the size of each sub-area). Peripheral strips used for calculating how quickly the illuminance falls off beyond the carriageway are excluded. The illuminance can be derived from metrics which have already been established for selecting the lighting class of the road.

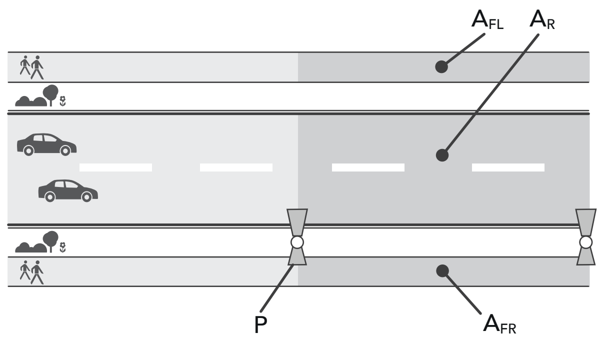

Figure 6 *Example layout for PDI/AECI calculation*

The full equation for calculating PDI is:

$$D_P = \frac{P}{\sum_{i=1}^{n} (\bar{E}_i \times A_i)}$$

with $\bar{E}_i$ being the maintained average horizontal illuminance of the sub-area, A_i being the size of the sub-area "i" lit by the lighting installation (in m²), and **n** being the number of sub-areas to be lit. For street lighting classes which do not use the maintained average horizontal illuminance (that is, street lighting classes other than M), section 4.2 of EN 13201-5 provides conversion guidelines.

Since the lighting class usually changes throughout different seasons and throughout the night, the PDI should be calculated separately for each relevant class. In order to compare the energy consumption differences between two different setups not just for a particular street lighting class, but throughout an entire year of operation, it is necessary to calculate the AECI. For this purpose, it is necessary to divide the year into separate operational periods where different values for P are applied. The full equation for calculating the AECI is:

$$D_E = \frac{\sum_{j=1}^{m} (P_j \times t_j)}{A}$$

with P_j being the total system power associated with the j[th] period of operation (in W), t_j being the duration of the j[th] period of operation profile when the power P_j is consumed (in h), **A** being the size of the area lit by the same lighting arrangement (in m²), and **m** being the number of periods with different operational power values P_j.

Total accumulated durations of t_j should add up to an entire year. Time periods when the lighting is not operational (such as during the day) should also be included in the calculation, since even during these periods the system still consumes standby power.

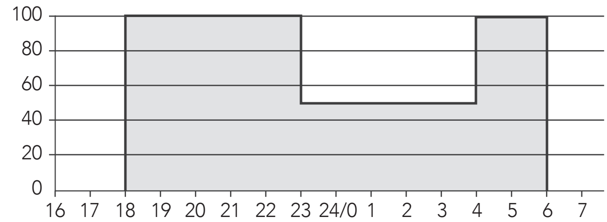

Figure 7 *Sample time-based light output: Full power during the evening and early morning, half power late at night*

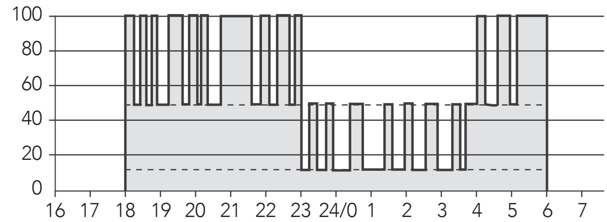

Figure 8 *Time-based light output with vehicle or presence detectors – full power when presence is detected*

Annex A of EN 13201-5 provides sample PDI/AECI values for a large range of lighting classes, carriageway widths, and lamp types (based on lighting products available in 2014). A few sample values are shown below (all for carriageway widths of 7 m).

Annex C of EN 13201-5 provides a simplified method for comparing lighting systems for M lighting classes based on the average maintained horizontal illuminance $\bar{E}$. Annex D presents a sample scheme for showcasing energy performance indicator information.

Table 7 *Sample D_P (in [W/(lx·m²)]) / D_E (measured in [(kWh)/m²]) values for a two-lane road for motorized traffic*

Lighting class	Lamp type				
	High pressure mercury	Metal halide	High pressure sodium	Low pressure sodium	LED
M1		45/5.0		34–41/4.0–5.3	25–32/3.0–3.8
M2	100/10.8	50/4.6		31–40/3.2–4.2	24–27/2.4–2.5
M3	84/6.0	47/3.6	40/2.8–3.1	34–38/2.5–2.6	23–25/1.5
M4	90/5.0	60/3.1	41–47/2.3–2.5	34–42/1.8–2.4	23/1.1
M5	86/3.2	30/0.9	47/1.7	38–45/1.1–1.6	24/0.8
M6	85/1.9	37/0.6		45–49/0.2–1.2	20–27/0.4–0.5

2.2.4 Example – roads in urban areas

The following section illustrates how the EN 13201 standard may be applied for different lighting situations in terms of road classification and requirements. The first example is an urban downtown location which includes a pedestrian crossing as well as a bicycle lane. The street is very crowded, causing severe traffic congestions during rush hours.

Figure 9 *Downtown location*

According to PD CEN/TR 13201-1:2014 this is a conflict area since there is a pedestrian crossing and thus the overarching lighting class will be C (lighting classes for conflict areas). Now Table 3 in the standard (Table 8) has to be used to determine the exact lighting class.

- Design speed or speed limit: during the rush hours traffic is relatively slow (≤ 40 km/h) which gives a corresponding weighting value of −1
- Traffic volume: since the traffic volume is high the weighting value is 1.
- Traffic composition: the pedestrian crossing and the bicycle lane give a mixed traffic composition. This leads to a weighting value of 1.
- Separation of carriageway: there is no such separation, thus the weighting value is 1.
- Parked vehicles: in general there are no parked vehicles, so the weighting value is 0.
- Ambient luminosity: the environment at rush hour times is bright and the ambient luminosity is high, so the weighting value 1.
- Navigational task: due to the pedestrian crossing the navigational task would be difficult, so the according weighting value is 1.

The sum of all weighting factors "VWS" is 4, which gives the final lighting class **C2** (C = 6 – VWS)

According to Table 2 in EN 13201-2, this results in the following requirements for the morning and evening rush hours:

- Minimum maintained average horizontal illuminance $\bar{E}$: 20 lx
- Minimum overall uniformity of the road surface luminance U_O: 0.4
- The informative Annex C of EN 13201-2 also suggests a maximum threshold increment f_{TI} of 15% (see Section 2.1.1.2 for a discussion of glare and threshold increment).

Table 8 *Choosing the lighting situation for a downtown location (according to standard EN13201-1:2014)*

Parameter	Options	Description*	Weighting Value V_w*
Design speed or speed limit	Very high	v ≥ 100 km/h	3
	High	70 < v < 100 km/h	2
	Moderate	40 < v ≤ 70 km/h	0
	Low	v ≤ 40 km/h	–1
Traffic volume	High		1
	Moderate		0
	Low		–1
Traffic composition	Mixed with high percentage of non-motorised		2
	Mixed		1
	Motorised only		0
Separation of carriageway	No		1
	Yes		0
Parked vehicles	Present		1
	Not present		0
Ambient luminosity	High	shopping windows, advertisement, expressions, sport fields, station areas, storage areas	1
	Moderate	normal situation	0
	Low		2
Navigational tasks	Very difficult		2
	Difficult		1
	Easy		0

* The values stated in the column are an example. Any adaption of the method or more appropriate weighting values can be used instead, on the national level

2.2.5 Example – roads in rural areas

Our second example is a route between two villages. Street lighting is not mandatory for such roads. However if street lighting is planned (for example, in order to reduce accidents) the lighting class and minimum criteria must be determined as usual.

Figure 10 *Rural location*

Since the situation is not classified as a conflict area (there is a combined bicycle/footpath next to the road, so cyclists and pedestrians are not allowed to use the road) and the average speed of the main road users is quite high, this road belongs to the lighting class M (lighting classes for motorised traffic).

Now, to determine the exact lighting class, Table 1 of the standard PD CEN/TR 13201-1:2015 (Table 9) has to be used.

- Design speed or speed limit: the average speed of the main road users lies between 70 and 100 km/h so the weighting value is 1.
- Traffic volume: In this example we will assume a moderate traffic volume which leads to a weighting value of 0.
- Traffic composition: Since there is a separate bicycle/footpath there are only motorised vehicles on the road and the weighting value is 0.
- Junction density: there are less than 3 intersections per km, so the junction density is moderate and the corresponding weighting value is 0.
- Parked vehicles: there are no parked vehicles so the weighting value is 0
- Ambient luminosity: the environmental brightness and thus also the ambient luminosity are low so the weighting value will be -1.
- Navigational task: since there are neither many intersections nor any different road users than motorised vehicles, the navigational task is easy and the weighting value is 0.

The final number of the lighting class is calculated with M = 6 – VWS. With an overall weighting value of 1 this leads to the lighting class M5.

According to the standards this provides the following criteria:

- Minimum maintained average road surface luminance $\overline{L}$: 0.5 cd/m²
- Minimum overall uniformity of the road surface luminance U_O: 0.4
- Minimum longitudinal uniformity of the road surface luminance U_O: 0.4
- Minimum overall uniformity of the road surface luminance U_{OW}: 0.15 (wet conditions)
- Threshold increment f_{TI} : 15 %
- Edge illuminance ratio R_{EI}: 0.3 (note that this applies to the side of the road without the combined bicycle/footpath – the separate path will have its own lighting class and criteria)

Table 9 *Choosing the lighting class for a rural area (according to standard EN 13201)*

Parameter	Options	Description*		Weighting Value V_w*
Design speed or speed limit	Very high	v ≥ 100 km/h		2
	High	70 < v < 100 km/h		1
	Moderate	40 < v ≤ 70 km/h		–1
	Low	v ≤ 40 km/h		–2
Traffic volume	High	Motorways, multilane routes	**Two lane routes**	1
	Moderate	35 % – 65 % of maximum capacity	15 % – 45 % of maximum capacity	0
	Low	< 35 % of maximum capacity	< 15 % of maximum capacity	–1
Traffic composition	Mixed with high percentage of non-motorised			2
	Mixed			1
	Motorised only			0
Separation of carriageway	No			1
	Yes			0
Junction density		Intersection/km	**Interchanges, distance between bridges, km**	
	High	**> 3**	**< 3**	**1**
		≥ 3	**≤ 3**	**0**
Parked vehicles	Present			1
	Not present			0
Ambient luminosity	High	shopping windows, advertisement, expressions, sport fields, station areas, storage areas		1
	Moderate	normal situation		0
	Low			–1
Navigational tasks	Very difficult			2
	Difficult			1
	Easy			0

* The values stated in the column are an example. Any adaption of the method or more appropriate weighting values can be used instead, on the national level

3. Lighting components and lighting design

3.1 Lighting system components

Street lighting system components can be divided into three broad categories:

- Optical systems, which cover luminaires (including reflectors, refractors and lenses), lamps or light sources, and the control gear.
- Support systems consisting of poles and their foundations.
- Electrical systems (including service cabinets) covering energy supply, control and metering facilities.

3.1.1 Optical Systems

3.1.1.1 Luminaires, lamps and light sources

For distinguishing the terms „luminaires", „lamps" and „light sources" a reference is made to the definitions, provided in the recent EU regulations 874/2012 (energy labelling of electrical lamps and luminaires) and 1194/2012 (eco-design requirements for directional lamps, LEDs and related equipment):

- "Luminaire" means an apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes all the parts necessary for supporting, fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply.
- A "Lamp" is defined as a unit whose performance can be assessed independently and which consists of one or more light sources. It may include additional components necessary for starting, power supply or stable operation of the unit or for distributing, filtering or transforming the optical radiation, in cases where those components cannot be removed without permanently damaging the unit.
- The term "light source" means a surface or object designed to emit mainly visible optical radiation produced by a transformation of energy. The expression "visible" refers to a wavelength range of 380–780 nm.

In this context a "luminaire" can contain one or more "lamps", whereas a "lamp" can be equipped with one or more "light sources".

3.1.1.2 Lamps

From a physical point of view all lamp technologies used for street lighting today transform electric energy into visible light. High intensity discharge lamps have been dominating in street lighting over decades, but as already mentioned in the previous section, LED technology is superseding all other lamp types, particularly for new street lighting systems. High pressure sodium (HPS) lamps remain as a relevant option, especially for some applications, such as for motorways. These lamps are very energy efficient but provide only low colour rendering; however this is not considered a problem in some areas of application. Metal halide lamps and low pressure discharge lamps are expected to be replaced by LED in the medium-term.

In LED lamps, light is produced by the so-called electroluminescence effect. As in other diodes electrons are moving from the cathode to the anode and emit a photon when falling to a lower energy level.

The wavelength of the light emitted, and thus its colour, depends on the materials used. For street lighting commonly blue LEDs are used, providing white light when encapsulated in a phosphor coating (yellow coating, cf. Figure 11 and Figure 12 illustrating different principles for white light generation based on phosphor coating). Blue-emitting LEDs currently have the highest efficiency of all LED types, with a power conversion ratio of 55 %. The remaining 45 % is transformed into heat. Since a higher junction temperature (the temperature of the LED semiconductor material) reduces both efficacy and lifetime, a good thermal design is necessary. In order to dissipate the heat, the LED chip and the reflector cup are mounted on a heat sink. This heat sink should in turn transfer the heat to the luminaire, which dissipates the heat externally.

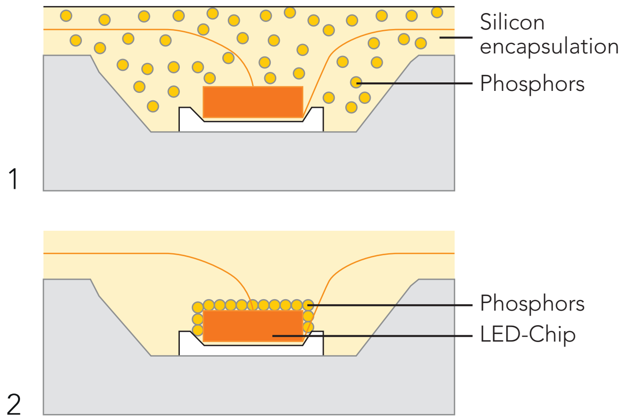

Figure 11 *Phosphor suspended in silicon encapsulation (1) and conformal phosphor coating (2)*

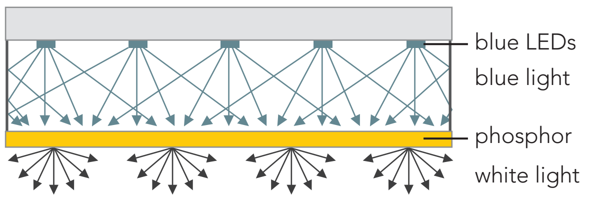

Figure 12 *Principle of a remote-phosphor LED module creating white light*

Another type of LED is the organic LEDs (OLEDs) which use a flat layer of organic molecules instead of semiconductors as the light-emitting substance. While there are many interesting applications for OLED (e. g. high end flat TVs) and the technology is advancing rapidly, it is not yet suitable for street lighting applications.

Since the luminous flux of one individual LED is fairly low compared to the lux required for street lighting, several LED chips are assembled in one circuit board and can be combined with additional components. Thus several levels of integration have to be distinguished. The following LED-related definitions are made in the Commission Regulations 874/2012 and 1194/2012:

- "Light-emitting diode (LED)" means a light source which consists of a solid state device embodying a p-n junction. The junction emits optical radiation when excited by an electric current.
- "LED package" means an assembly having one or more LED(s). The assembly may include an optical element and thermal, mechanical and electrical interfaces;
- "LED module" means an assembly having no cap and incorporating one or more LED packages on a printed circuit board. The assembly may have electrical, optical, mechanical and thermal components, interfaces and control gear;
- "LED lamp" means a lamp incorporating one or more LED modules. The lamp may be equipped with a cap;

This distinction is in line with the segmentation of LED products commonly established within lighting industry [RL], excluding level 2 (Table 10).

Table 10 *Levels of LED integration*

Integration Level	Description
Level 0	LED chip (or die)
Level 1	Packaged LED including electrical connection, mechanical connection and protection, heat dissipation device and basic optical components.
Level 2	Assembly of various LEDS (LED cluster) on a printed circuit board.
Level 3	LED module (or LED engine). A module with LED cluster, heat sink, electrical driver and sometimes an optical device. The LED module functions as a lamp.
Level 4	Luminaire consisting of LED module (Level 3) and housing and secondary optics
Level 5	LED lighting system including control features

The operating temperature of the LED chip is a critical aspect, especially influencing the efficacy and the lifetime. The performance data of LED chips is specified for a temperature of 25 °C. However actual temperatures in normal operating conditions can easily reach 60–90 °C, causing a drop of lumen output by up to 40 %. However blue LEDs are less affected from increased operating temperatures (with a decrease of flux by 5 to 20 % at 80 °C chip temperature).

The lifetime of LED light sources may exceed 100,000 h (specified for L80, c.f. chapter 2.1.4), but is strongly dependent on the actual operation temperature and the effectiveness of the luminaire's thermal management, ensuring a sufficient heat dissipation.

Commonly and in contrast to other lighting technologies LED modules are affixed to the luminaire and are not designed to be replaced as standardised components. This may challenge a long term repair and replacement strategy. Several industry actors have been engaged in establishing an open standard called Zhaga for interoperability and interchangeability of LED modules and luminaires, offered from different suppliers. However Zhaga certified products (LED engines, modules, and luminaires) still represent only a niche of the overall market.

LEDs cannot be operated with mains supply voltage (AC). Thus a control gear ("driver") is needed, with its main function to provide a stabilized DC voltage. Depending on the quality of the driver, power losses can vary between 10% and 30% of the nominal wattage of the light source. Poor quality drivers may have losses up to 50% and may reduce the lifetime of the light source [RL]. An important secondary function of the driver is dimming, which is discussed in section 3.3.4.

3.1.1.3 Luminaires

The luminaire is the complete lighting apparatus consisting of the housing as well as all parts required for mounting and function, including the lamps, control parts, control gear, wiring and so forth. LED light sources are usually mounted in specifically designed flat luminaires that make optimal use of their optical properties. Other LED luminaire types modelled after classical luminaires are generally intended as replacements of classic non-LED luminaires. These designs typically do not make use of optimized optical and heat dissipation systems available for LED technology. Nevertheless, their application may still be appropriate for locations where comprehensive refurbishing of the lighting system is not feasible.

The test standard for luminaires used by manufacturers is IEC 60598-2-3, which provides general recommendations for luminaires and their covering. Luminaires should be corrosion resistant or protected from corrosion with appropriate finishes. Luminaires contain optical elements like reflectors, refractors and lenses which create the desired light distribution and ensure glare control and limitation of light pollution.

Reflectors are used to redirect the light output. The reflector mirrors create multiple images of the light source thereby supporting a relatively uniform luminance pattern on the lit surface. Furthermore reflectors support minimized light pollution and glare (see sections 2.1.1.2 and 2.1.1.6).

Refractors or prismatic lenses redirect the light from the lamp and the reflector and provide additional protection against damage. They are most commonly used in cobra head luminaires.

Lenses allow further directional controlling of the light and are directly fitted onto LEDs. Similar to the other components mentioned they support the redirection of light, reduction of glare and ingress protection (see section 2.1.2.1).

Flat Luminaire | High Mast Style Luminaire | Cobra Head Style Luminaire

Figure 13 *LED Luminaire Types*

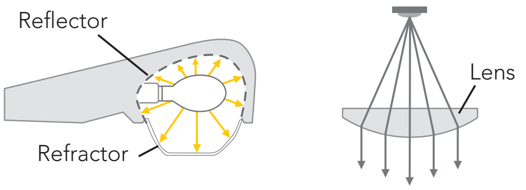

Figure 14 *Reflector, refractor and lens in street lighting luminaires*

In modern LED luminaires advanced lens-type refractors can be fitted on each individual LED, which makes it possible to modify the light distribution by switching or dimming LEDs with different lenses. This allows for greater flexibility in fitting the light distribution to luminaire spacing, road width, road-surface reflection properties, and changing weather conditions [RL].

The CIE Technical Report 115:2010 introduced luminous intensity classes for luminaires, which define criteria for maximum luminous intensity values for different angles of elevation. The classification includes the levels G1 to G6, representing increasingly stringent criteria for higher angles (and thus reducing light pollution and glare), [CIE].

The components of a luminaire should be modular to allow replacement in case of failure or upgrades by an identical or compatible component thereby avoiding the replacement of the luminaire as a whole. As explained in the previous section, heat dissipation is especially important for LED luminaires. Besides ensuring good heat conduction between the lamp and the luminaire, the following features of the luminaire improve heat dissipation:

- The luminaire volume: the greater the volume, the less the temperature within the luminaire.
- The heat conduction properties of the luminaire casing, which determine how fast the heat transfers into the surrounding air: Most metals provide suitable heat dissipation characteristics, while plastics are thermal insulators and thus generally unsuitable for LED luminaires.
- Cooling fins: may also be used for improving heat transfer into the surrounding, as they increase the surface area of the luminaire.

Luminaires are generally rated by their maximum ambient temperature Ta under which they can be operated safely. If no Ta value is given, they are intended for a maximum ambient temperature of 25 °C.

Mark of conformity and quality marks for street lighting luminaires

CE

Any product placed on the market within the European Union must comply with all relevant EU directives. With the CE marking, a company legally bindingly confirms the conformity of the corresponding product with the relevant regulations. Since 1997, a CE mark must be affixed to all products traded in Europe which are affected by the CE marking directives.

The CE mark (Communautés Européennes, European Community) is not a test mark like the ENEC or other national quality marks, but a conformity marking. It has to be highlighted that the CE symbol is not issued by a (third party) testing institute, but by the manufacturer himself.

The monitoring authorities recognize a product with a CE marking without further testing as being marketable. Conformity is only checked by market surveillance authorities within spot checks or if products are suspected being non-compliant.

For street lighting luminaires the CE mark of conformity covers the following legislation

- Directive 2014/35/EU on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits (low voltage directive)
- Directive 2014/30/EU on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast)

ENEC

The ENEC mark (European Norms Electrical Certification) is a European safety mark with uniform test conditions across Europe. The ENEC Agreement describes the procedure for the granting and use of a commonly agreed mark for certain electrical equipment complying with European Standards. At present the following 20 countries have signed the agreement: Austria, Belgium, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Norway, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom.

The ENEC symbol confirms that the product complies with the corresponding requirements of the European Union. The ENEC mark may be awarded by a national certification body which is party to the ENEC Agreement. The number after the ENEC mark indicates which test center has been certified in which country (e. g. ENEC 03 for Italy).

The joint test conditions are stipulated in the EN 60598 series of standards. In order to ensure the product quality guaranteed by the ENEC mark, manufacturers must also have a quality assurance system.

A product with ENEC marks from another European country is treated as if it had been certified by the national inspection body in its own country. This simplifies the free movement of goods in the European economic area, including Switzerland – and increasingly in the Eastern European market.

3.1.2 Support Systems

Poles must correspond to the EN 12767 ("Passive Safety of Support Structures for Road Equipment") standard which specifies criteria in order to minimize the danger to vehicle occupants in case of collisions. According to the standard, support structures of road equipment are classified into three different categories of passive safety:

- **High energy absorbing (HE)**
- **Low energy absorbing (LE)**
- **Non-energy absorbing (NE)**

Energy-absorbing support structures will slow down the vehicle significantly during a collision and reduce the risk of secondary collisions. Non-energy absorbing structures will allow the vehicle to continue with only slight reductions in speed, which reduces the risk to the occupants from the initial collision but increases the risk of secondary collisions – including with other traffic participants. The type of pole chosen for a particular stretch of road can be selected by the responsible levels of administration based on their own evaluation of their local needs. For instance HE poles may be installed in urban areas in order to reduce the secondary risk for other traffic participants.

Four levels of occupants' safety are specified for support structures, with level 4 representing non-harmful support structures that are assumed to cause only minor damage. The other three levels are determined by impact tests using lightweight passenger cars with speeds of 35, 50, 70, and 100 km/h. The test data is used to derive the acceleration severity impact (ASI) and the theoretical head impact velocity (THIV) metrics, which describe the danger to passengers [TRB].

With stationary light masts, a lifetime of several decades is intended. Light masts made of steel are nowadays galvanized. In the past, they were protected against corrosion by rust protection. Stainless steel versions are only used in representative areas. The electrical or other installations are serviced and exchanged much more frequently than the mast itself. Environmental influences such as sun, ordinary rain and wind are rather uncritical for the components. However, major storms, pending snow or even ice curtains can pose a threat to the poles.

The arrangements of the masts as well as their height are technical decisions. This decision is based on the geometry of the road, the characteristics of the system, the ground conditions of the road, the physical characteristics of the mast, the environmental requirements, the space available for maintenance, the available budget, aesthetics and lighting objectives. The most common arrangements are shown below.

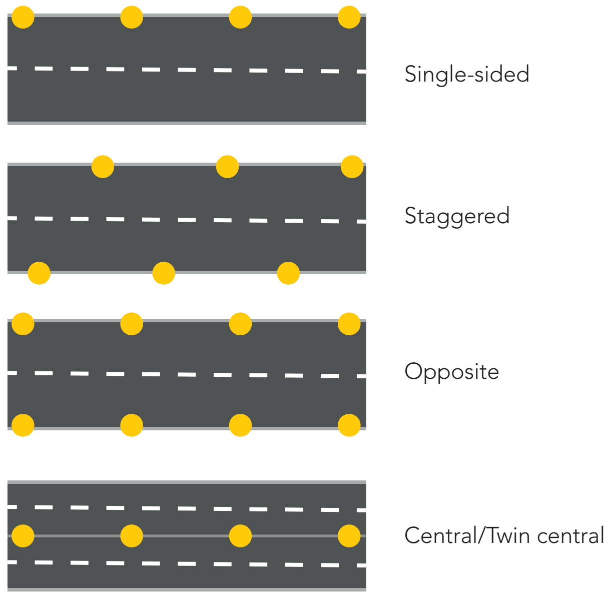

Figure 15 *Lamp arrangements*

The lamp arrangement chosen determines the minimum mounting height of the luminaire as a factor of the effective road width (as measured from the horizontal position of the luminaire to the far side of the road).

- **In single-side arrangements**, the effective road width can be up to equal to the mounting height of the luminaire. Furthermore, unlike with the other arrangements the luminance of the road surface will not be equal on both lanes of the road.

- **In staggered arrangements**, the effective road width can be up to 1.5 times the mounting height of the luminaire. Their longitudinal luminance uniformity is generally low and creates an alternating pattern of bright and dark patches. However, during wet weather they cover the whole road better than single-side arrangements.
- **In opposite arrangements**, the effective road width can be around 2 to 2.5 times the mounting height of the luminaire. If the arrangement is used for a dual carriageway with a central reserve of at least one-third the carriageway with, or if the central reserve includes other significant visual obstructions (such as trees or screens), it effectively becomes two single-sided arrangements and must be treated as such.
- **In central arrangements**, the luminaires are hung from so-called span wires strung across the road, usually between buildings. The effective road width can be up to two times the mounting height of the luminaire.
- **In twin-central arrangements** – where two luminaires are installed at the centre, back to back – the effective road width can be up to equal the mounting height of the luminaires. Provided that the central reserve is not too wide, both luminaires can contribute to the luminance of the road surface on either lane, making this arrangement generally more efficient than opposite arrangements. However, opposite arrangements may provide slightly better lighting under wet conditions.

Deciding on the exact pole positions and luminaire mounting height is part of the design process and is usually done with specialized software. The goal is not only to maintain a minimum luminance, but also a minimum luminance uniformity, which depends on the luminous intensity distributions of the luminaires in the street lighting installation. It should be noted that while many LED products are designed as a replacement of existing luminaires (thus making use of existing poles), this often does not take full advantage of modern LED luminaire designs which are capable of far more uniform luminous intensity distributions than comparable HPS or MH luminaires [LRT4].

3.1.3 Electrical Systems

The grounding conductor should be connected to the metal ground box lids exposed metal conduits, metal poles, as well as any supplemental ground rods installed into the pole foundations.

The resistance of the wires and cables of a particular street lighting circuit will cause the voltage to drop, leading to an inefficient operation. In order to ensure that all luminaires within a particular circuit receive a minimum level of voltage supply, the voltage drop between the feed point and the furthest luminaires should not exceed 3%.

The service cabinet should be a rain-tight enclosure sealed with a pad-mounting gasket [IIEC].

3.2 Street lighting control systems

Active control of street lighting systems allows for significant energy savings, but potential savings must be weighed against added complexity and cost. Based on the type of management there are three types of lighting control systems: Autonomous control, centralized control, and dynamic control.

3.2.1 Autonomous control

With autonomous street lighting control, the luminaires are pre-programmed (usually by the manufacturer) with fixed time periods for operation. This is by far the simplest and cheapest solution, since it doesn't require further control and network systems. However, since the programming is usually limited there is often no way to adjust control for weekends and holidays. Furthermore, internal timers may not be accurate, and any upgrade of the system requires changes in every lamp post. Alternatively, sensors might detect the ambient light at every light post and decide on whether to activate the lamps. However, this causes additional expenses.

3.2.2 Centralized control

In centralized street lighting control, a central system sends the control signal to all luminaires within a group (usually by a signal sent via the power line). This setup is comparably simple and cheap to implement but does allow for some flexibility in adjusting the lighting to changing needs. For instance, a central light sensor could determine when to switch on all lights of a given group which for example (unlike purely time-based management) allows for adjustment to local weather conditions. Such sensors should be cleaned on a regular basis in order to guarantee their smooth operation [BFE] .Other options include time-based dimming which reduces or switches off the light of certain lamps at specific times and areas (e.g. late at night when the expected traffic volume is low). While the reduction of energy costs and light pollution (see section 2.1.1.6) may be substantial, this may put traffic participants at increased risk if their ability to navigate obstacles is impaired [CEE]. Thus specific applications need to be assessed carefully.

Furthermore, the information flow is in one direction only. While the central node can determine the status of the groups of lamps, it does not receive information about their individual status or any other local conditions.

Both centralized and dynamic control systems require the implementation of ICT (Information and Communications Technology) systems of varying degrees of complexity. While they provide additional options for saving energy, they also require additional resources and expertise for implementation and maintenance. Added complexity increases the risks of system failures [HCS]. Thus, procurers and planners should consider whether expertise and support is available after implementation, even on relatively short notice.

3.2.3 Dynamic control

With dynamic street lighting management, the greatest extent of control is possible. Not only can the lamps be controlled either in groups or on an individual basis, but the central control server can also collect information on their status depending on the options installed (e.g. failures, energy consumption, operating or ambient temperature, ambient light, traffic, and the presence of pedestrians). Changes to the programming can also be done on the central control server instead of requiring changes to the physical hardware.

However, as outlined above this added flexibility comes with considerable added complexity and thus added costs. The control software must be implemented and maintained, and the local operators in charge of the system must be trained in its use. Furthermore the added complexity increases the risk of programming failures. The lamps should be installed with fail-safe systems that guarantee basic traffic safety at night even when receiving no or erroneous commands from the control system [BFE].

State of the art intelligent management systems are generally controlled by a central command centre, which is often a server maintained in the offices of the local authorities. This server monitors a high number of lamps and sends commands which determine the status of the individual lamps. The commands are not received by the lamp control systems directly but first pass through concentrators which then pass on the messages to local area networks consisting of a limited number of lamps and the controlling actuators [PE].

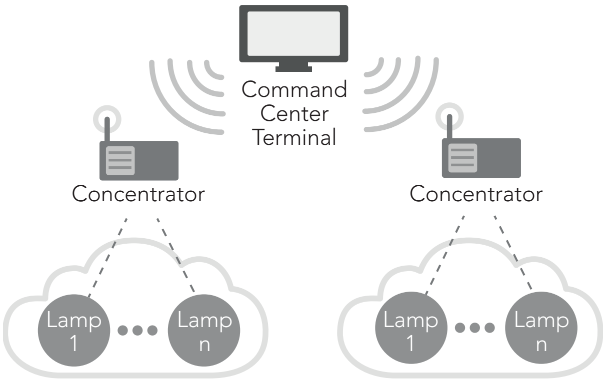

Figure 16 *Street lighting control system architecture*

Two technological concepts are required for deciding on the control system architecture – the communication technology (how the information is transmitted) and the communication protocol (how the information is encoded).

There are two layers of communication in a street lighting system that need to be bridged with communication technology: Command centre to concentrators, and concentrators to individual lamps. They can either transmit information via cable or as wireless signals, and both options have implications for the communication protocols that are available.

Cable-bound communication between the command centre and the concentrators generally uses standard Ethernet communication protocols, which are a well-established technology [PE]. While Ethernet cables are theoretically possible between the concentrators and the lamps, this would require additional cabling and thus additional costs. Instead, cable-bound local networks for street lighting generally use power-line communications (PLC), which modulate the signals of their power line in order to exchange information.

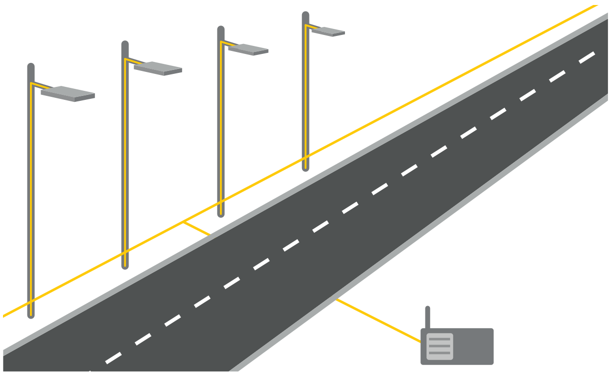

Figure 17 *Power-line communication*

Wireless communication between the command centre and the concentrators require that the comparably large distances can be bridged via wireless signals. Suitable protocols include Wi-Fi (802.11), GPRS (General Packet Radio Services) or WiMax.

Wireless signals between the concentrators and the individual lamps can be implemented as a mesh, which has the advantage that a lack of line-of-sight doesn't break the connection between individual nodes. If necessary, the signal strength can be boosted via repeaters. Suitable protocols for this layer include:

- DALI (Digital Addressable Lighting Interface): An IEC-adopted standard that has been developed for controlling ballast circuits used for lighting equipment monitoring. However, it can only control up to 64 nodes.
- ZigBee, a low-cost, low-power, and low-data rate alternative for wireless networks. However, it has shortcomings in terms of package delays and may cause slowdowns in network performance.
- 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks). This standard does not define a specific routing protocol for a particular system. This allows for more flexibility but requires additional effort defining the protocols used for a particular installation [SEN].

Figure 18 *Wireless communication*

3.3 Street lighting control strategies

Various strategies at different levels of complexity for street lighting control have been developed over the years, each with its own advantages and disadvantages. Some may even be combined for more complex strategies.

3.3.1 Astronomical timer

Astronomical timers have precise information about sunrise and sunset times for any given geographical position. These can be calculated in advance with a very high level of accuracy for long time spans. However, lighting control strategies based on astronomical timers might not take specific geographic aspects into account, such as large hills or mountains blocking the sun at dawn or dusk. Furthermore, astronomical timers can make no predictions about weather conditions such as storms which might require artificial lighting even during daylight hours.

Astronomical timers might establish a simple on-/off scheme for illumination that specifies the time of activation of the lighting in the evening and the deactivation in the morning. Alternatively it might specify periods later at night during periods when less traffic is expected during which the lighting remains active but at reduced operating intensity.

One of the main advantages of astronomical timers is that they do not require any complex ICT systems to operate.

3.3.2 Daylight harvesting

In contrast to using astronomical timers, daylight harvesting strategies use photo sensors to detect the ambient light and adjust the artificial lighting if the ambient light levels fall or increase beyond certain threshold values. This approach works especially well with dimming (see below) and can adjust to extended periods of twilight as well as inclement weather. However, the photo sensors require regular cleaning in order to ensure their proper function. Furthermore it must be decided whether a single photo sensor is controlling the lighting for a large area or whether each group of lamps or even each individual lamp has its own sensor. The first option reduces the system complexity but cannot reflect all localized conditions (such as especially shaded areas or smaller weather systems) and represents a single point of failure for the system.

The second option allows for more flexibility, but also requires the purchase of a large number of additional sensors and requires more maintenance for keeping the sensors clean.

The photo sensors can be embedded into a larger ICT infrastructure, which (depending on setup) can enable real time monitoring of the road illuminance. Thereby any problems with insufficient lighting can be quickly identified and addressed.

3.3.3 Traffic detection

On many roads, traffic may be consistently low, especially late at night. Thus, reducing their level of illumination in compliance with the requirements stipulated in EN 13201 offers potentially large energy savings. In order to ensure that traffic participants can still navigate these roads safely, traffic detection systems can be installed which increase the level of illumination again when needed. The most common technology for detecting traffic – whether motorized vehicles, cyclists, or pedestrians – are motion sensors. Types of motion detectors include the following:

Ultrasonic motion detectors detect the shift in sound waves bouncing back from a moving object. This type of sensor does not require line of sight. It is cheap, can detect objects irrespective of their materials, and is little affected by air flows of up to 10 m/s (36 km/h). However, they have a low detection range and can be affected by humidity and high temperatures.

Microwave motion detectors detect shifts in microwaves bouncing back from a moving object, similar to radar speed guns. They are able to detect even small motions and are not affected by the ambient temperature of objects. However, they are costly and may cause false detection due to movements outside the specified zone.

Infrared sensors detect the heat of an object or a person relative to their surroundings. They are purely passive sensors – thus, they do not emit sound or radiation in order to collect information. However, they might trigger false detection from warm air, rainfall, or hot objects.

Video processing uses video cameras as smart sensors, identifying moving objects via smart algorithms. They can monitor a larger area than other detection system and detect not only the motion but also the presence of objects. They also have a low probability of false responses. However, the data processing algorithms are fairly complex, resulting in both added cost for the software as well as added electricity consumption due to their processing power requirements. Furthermore they are dependent on light, though this can be compensated with infrared filters to some degree.

Motion detection systems can also be combined so that the disadvantages of one type are compensated by the capabilities of another.

Once the need for added illumination is detected by the sensors, the system should ensure that the usual requirements for the relevant street lighting class (see section 2.2.1) are met. This means that a motion sensor attached to a particular lamp pole generally should not just be used to activate that particular lamp, but also one or more adjacent lamps so that traffic participants are not subject to glare from rapidly changing lighting conditions.

Any motion detector-based systems that are intended to cover more than pedestrian-only areas almost invariably require integration into a larger ICT setup. However, this has the added advantage of allowing traffic information data which can be useful to traffic controllers, urban planners, emergency services and other agencies.

3.3.4 Dimming

Depending on traffic, weather, and ambient lighting conditions it may not be necessary to operate lamps at full power throughout the night. By combining proper astronomical timers, daylight harvesting, and traffic detection schemes with dimming, huge energy savings can be attained – in some projects, up to 85% savings were achieved. Furthermore, gradually increasing and decreasing the illumination reduces discomfort glare for nearby residents. LEDs are especially suitable for dimming-based strategies as they can be dimmed smoothly with almost no technical complications, whereas other lamp types used in street lighting cannot be dimmed, produce drastic colour shifts when dimmed (high-pressure mercury and metal halide lamps) or are limited in how far they can be dimmed.

3.3.5 Considerations

Both dynamic street lighting control and advanced control strategies such as daylight harvesting and traffic detection are rapidly changing technological fields, and as such require especially careful consideration of the potential barriers and limitations to their successful implementation.

National and local laws, regulations, and standards for street lighting frequently do not take the latest technological developments into account. Thus care must be taken to ensure that the proposed lighting control systems meet all legal requirements. An additional concern is liability: if the system fails due to some technical defects, it must be clear which party is responsible for the failures.

As implementing dynamic street lighting control can result in a system of considerable complexity, the tenderer in charge of implementing it should also be in charge of support and maintenance, which will likely require extended service contracts. This is especially important if the implemented solution features systems and components from multiple tenderers that require integration and occasional updates. A proven track record with dynamic street lighting systems is recommended as a criterion for the selection of the tenderer.

Luminaires should be programmed with a "default" state it can revert to in case it receives no or erroneous control signals. This default state should represent basic time-based lighting control fulfilling legal standards without any dynamic features. Furthermore, in case of total system failure, designated operators should be able to put parts or the complete lighting system into default state on short notice without requiring intervention of external experts.

4. Procurement of lighting systems

4.1 Introduction

The following chapter is dedicated to the procurement of energy efficient high quality street lighting. A comprehensive table of the set of recommended PremiumLight-Pro procurement criteria is also provided in the appendix of this brochure.

The recommended set of PremiumLight-Pro requirements covers basic criteria for the selection of the tenderer (called selection criteria in the following sections), specific technical requirements, demonstration of which should be mandatory for all tenderers, and award criteria. For the award criteria a scoring approach is proposed. Furthermore general technical specifications as well as contractual issues typically required for tenders are provided. Table 11 below shows an overview of the set of specifications and requirements.

Table 11 *PremiumLight-Pro Minimum Requirements and Award Criteria*

A) General technical specifications	
Plan/layout of road system Specification of streets and paths and appropriate related technical specifications (Illuminance, uniformity, maintenance factor etc.).	The procurer shall specify the streets and paths for which the street lighting system will be designed or lighting system components shall be procured. The system shall be specified based on the standard EN13201 and the related national standards. Among others the procurer shall specify: • Illuminance levels, • uniformity levels, • lighting system maintenance factors according to EN 13201 or based on specific needs.
Lighting control features	The procurer shall specify one of the following three options. • No lighting control features shall be considered because lighting control respectively dimming is not deemed appropriate by the procurer for the specific lighting system • The procurer is fully aware of the lighting control/dimming options suitable for the specific lighting system and specifies detailed requirements for a lighting control system. • The procurer is not in a position to specify optimal lighting control features for the lighting system but requests the tenderer to provide an offer for a dimmable system accompanied by a transparent LCC calculation.

A) General technical specifications	
Energy consumption metering	The procurer shall specify one of the following three options: • no energy consumption metering shall be considered because metering is not deemed appropriate by the procurer for the specific lighting system. • The procurer is fully aware of the metering options suitable for the specific lighting system and specifies detailed requirements for the metering concept. • The procurer is not in a position to specify optimal metering for the system but requests the tenderer to provide an offer for a suitable metering accompanied by a transparent LCC calculation

B) Selection criteria		
	Mandatory requirement	Award criterion
Know-how and experience of the design team and the installation team	✓	
Capacity of tenderer to deliver within specified timeframe	✓	
Compliance with ISO and EN standards	✓	

C) Technical requirements and award criteria		
Energy criteria – System level	Mandatory requirement	Award criterion
Annual energy consumption and power density indicator	(✓)	✓
Power Factor	✓	✓
Lighting control features: optional, as specified in general technical specifications above		✓
Energy consumption metering: optional, as if specified in general technical specifications above		✓
Energy criteria –component level (for projects only involving component replacement)	Mandatory requirement	Award criterion
Luminaire energy efficiency	✓	✓
Driver energy efficiency	✓	✓
Quality and design criteria	Mandatory requirement	Award criterion
Colour temperature	✓	
Colour rendering	✓	
Colour consistency	✓	✓
Illuminance and luminance	✓	
Light distribution, uniformity of illuminance	✓	✓
Light pollution (ULOR)	✓	
Glare protection (disability and discomfort glare)	✓	✓
Ingress protection (IP rating)	✓	
Impact Protection (IK rating)	✓	
IEC protection	✓	
Overvoltage protection	✓	
Mark of conformity for all components (ENEC, national regulations)	✓	
Lifetime	✓	✓
Warranty	✓	✓

C) Technical requirements and award criteria		
Availability of spare parts	✓	✓
Easy of repair and recycling	✓	✓
Design		✓
Quality criteria for component level projects only		
Luminaire life time	✓	✓
LED module lifetime	✓	✓
Driver life time	✓	✓

D) Cost criteria		
TCO calculation (recommended option)		✓
Investment costs (fall back option)		✓

E) Contractcual issues		
Putting into service of lighting systems and controls	✓	
Correct installation	✓	
Reduction and recovery of waste	✓	

4.2 General specifications

Table A) covers some essential general specifications to be considered during the initial stage of the tender process. At that stage the general layout of the lighting system and essential performance requirements shall be specified according to EN 13201 or based on specific needs. Among others this includes:

- Illuminance levels
- Uniformity levels
- Lighting system maintenance factors

Furthermore lighting control features and energy consumption metering features shall be specified.

4.2.1 Specification of the lighting system

As an early preparatory step in the procurement process the procurer shall specify the road system for which the lighting system will be designed. Street types shall be specified based on international standards (EN 13201) or if desirable on national/local standards.

4.2.2 Lighting control features and communication systems

During the initial stage of the process it is necessary to assess and specify whether and what kind of lighting control features should be considered. While simple control options will be desirable as a minimum functionality for most types of street lighting systems, comprehensive smart control features may be appropriate only in specific cases. Adequate lighting control functionality should be specified for the particular road type. The evaluation of different options may require support from independent consultants. Smart control features also have to match safety and quality aspects. Several technical options are described in chapter 3 of these guidelines. Different technical options shall be assessed in terms of life cycle costs. Furthermore the following requirements should be met in terms of compatibility and communication:

Communication

PremiumLight-Pro requirement:

A communication system shall be available, capable of communication with the control gear of the individual luminaires. Power-line communication (PLC) represents the minimum level of technology capable of meeting this criterion, but more advanced communication systems may be applied. The control gear shall be programmable and send notifications in case of equipment failure.

<u>Compatibility with control functionality</u>

PremiumLight-Pro requirement:
Luminaires shall be compatible with dimming and other control features (e. g. time switch, motion control, daylight control etc.).

Optional requirement:
Luminaires shall be equipped with integrated constant flux control systems. This ensures that the luminaire will have a constant flux output throughout its lifetime despite the gradual decline of flux output by the LEDs over time.

Verification
Documentation describing the dimming method and the dimming interface shall be provided by the tenderer.

As optional requirements, it is beneficial if the ICT systems implemented for lighting management are modifiable, modular, and open. Modifiability ensures that the lighting control system can be upgraded or extended when needed, allowing for additional functionalities that are not part of the original system during installation. Modularity requires adherence to standards in its building blocks of the ICT system and interfaces between building blocks, allowing changes to part of the system without overhauling the system as a whole. Criteria useful for assessing modifiability and openness include:

- Schedule of upgrades/updates
- Scalability of the system
- System boundaries and inherent limitations
- Module interfaces and standardization of the software interfaces
- Interoperability and interchangeability of modules
- Accessibility of the network, infrastructure and data shared with the system
- Connectivity of the system to other relevant systems, applications, and domains

4.2.3 Energy consumption metering

In parallel to the specification of control features the potential need for metering functionality shall be clarified. Options and general recommendations concerning metering are covered in chapter 3. The assessment of a lighting system in terms of optimised maintenance and operation, respectively electricity costs and energy consumption requires appropriate metering. AECI values can only be verified by measurements. Furthermore metering allows quick detection of failures and need for maintenance. Metering can be done at different levels in the system, involving also different levels of complexity. Appropriate options shall be considered and compared.

PremiumLight-Pro-Requirement:
Should lighting control options and metering options be selected as appropriate for the project, the specific functionality is to be described in the call for tender. Costs and benefits of the lighting control and metering shall be included in the total LCC/TCO calculation.

Verification
Tenderers shall offer options for metering and shall declare costs and benefits on the basis of TCO/LCC considerations.

4.3 Selection criteria

Selection criteria specify the basic requirements to be met by the tenderer on the whole. Criteria, among others typically cover the expertise, capacity and the certification of the tenderer.

4.3.1 Know-how and experience of the design team and the installation team

The design and the installation of the lighting system may be done by different companies or alternatively by one single tenderer. For both situations the tenderers shall confirm that the design and installation tasks will be undertaken by a team with adequate professional expertise.

PremiumLight-Pro Requirement:
The tenderer (or the experts specified for the project) has successfully executed a minimum of 5 relevant projects for street lighting involving LED technology in the last 3 years. Reference projects should be of a size/complexity comparable to the project planned.

Verification
The tenderer shall specify the persons responsible for the project and shall provide information on educational and professional qualifications, relevant experience, and related certificates. Furthermore the tenderer shall provide a list of comparable lighting projects that have been designed respectively implemented over the last three years. In case some of the work is to be sub-contracted, similar information from subcontractors shall be provided. Project sizes for example can be specified based on the number of lighting points.

4.3.2 Capacity of the tenderer

PremiumLight-Pro Requirement:
The tenderer shall show and confirm the capacity for the execution of the project within the specified time-frame.

Verification:
The tenderer shall specify the resources dedicated to the project and the concrete timeline for the project.

4.3.3 Compliance with the relevant international and national standards

PremiumLight-Pro Requirement:
The tenderer shall comply with the relevant international and national standards.

Verification:
The tenderer shall declare and confirm compliance with the relevant standards specified.

4.4 Technical requirements (mandatory and award criteria)

The technical requirements cover quality and energy requirements which are partly specified as mandatory criteria and as award criteria.

4.4.1 Energy related criteria

4.4.1.1 Luminaire efficacy

The following requirements specify a minimum efficacy for LED luminaires. Luminaire efficacy varies with the colour temperature of the light source. For that reason different efficacy requirements for different colour temperature levels are proposed. In particular luminaires with very low colour temperature (e. g. ≤ 2000 K) provide comparably low efficacy. Requirements for luminaire efficacy will be updated every year with new levels to be specified during fall 2018 for the year 2019.

PremiumLight-Pro Requirement:
The following efficiency requirements for luminaires are specified for 2017 and 2018:

- 4000 K: ≥120 lm/W
- 2700–3000 K: ≥ 105 lm/Watt
- ≤ 2000 K: ≥ 80 lm/Watt

Luminaries with very low CCT (amber type) should be used for sensitive areas/applications only, thus their application should be based on adequate justification (suburban areas, areas with specific nature preservation aspects).

The PremiumLight-Pro criteria are intended for LED lighting only, thus efficacy levels for traditional technologies are not considered.

Verification
The tenderer shall specify and confirm the efficacy of the components in the technical documentation of the tender. Luminous flux and power shall be declared according to the appropriate standards.

4.4.1.2 Annual energy consumption indicator and power density indicator

The energy consumption criteria "Annual Energy Consumption Indicator" (AECI) and "Power Density Indicator" (PDI) are the main indicators for the assessment of energy consumption and efficiency at the lighting system level (for details see pp 18, chapter 2).

Calculation of AECI and PDI is based on hardware component data and therefore verification of product information is necessary to demonstrate the correctness of calculations. AECI covers aspects such as dimming, over-lighting or constant light output (CLO) (EN 13201-5:2016), and is therefore the primary preferable indicator in many situations.

In this first version of PremiumLight-Pro criteria AECI and PDI are only included as award criteria. Thus no minimum requirements are specified.

For cases where the procurer wants to specify mandatory minimum requirements a possible approach is indicated further below.

PremiumLight-Pro-Requirement:
PDI and AECI shall be calculated by the tenderer as specified in EN 13201-5:2016 and further explained in chapter 2 of this document:

Power Density Indicator (PDI)

$$D_P = \frac{P}{\sum_{i=1}^{n} (\bar{E}_i \times A_i)}$$

Annual Energy Consumption Indicator (AECI)

$$D_E = \frac{\sum_{j=1}^{m} (P_j \times t_j)}{A}$$

D_P (PDI): Power density indicator
D_E (AECI): Annual Energy Consumption indicator
P: Power (W)
$\bar{E}_i$: maintained average horizontal illuminance (lx)
A: lit area (m^2)

PDI and AECI shall be calculated by the tenderer in a transparent way and be verified by measurements for a specified road segment. AECI typically includes dimming options.

Verification
The tenderer shall calculate and provide the AECI and PDI values in a transparent way (according to the standard EN 13201-5:2016). The tenderer shall supply the photometric file of the luminaires and the component parameters required for AECI and PDI calculation. Furthermore the technical specifications of the light source shall be provided (declarations shall be based on state-of-the-art measurement methods including harmonised European standards). In cases where dimming is applied, assumptions shall be specified in accordance with EN 13201-5:2016 (see chapter 2 (pp13)) for a more detailed discussion of the energy performance indicators).

Alternative approach for procurers who intend to specify a minimum requirement for energy efficiency at the system level
While PremiumLight-Pro does not include mandatory minimum efficiency requirements at the lighting system level, a possible approach is indicated that may be used by procurers interested in system level requirements. The approach is currently proposed and discussed by EU-GPP. The proposed minimum requirements for PDI and AECI are calculated based on the parameters illuminance, utilance, luminaire efficacy, system maintenance and dimming factor (EU-GPP Draft August 2017 by JRC Seville). We suggest using a slightly simplified approach involving road width instead of utilance which is shown below:

$$PDI < M/(\eta \times Fm \times 0.07 \times RW)$$

$$AECI < M \times PDI \times Fdim \times Em \times T \times 1\ kW/1000\ W$$

Fm: Lighting system maintenance factor
RW: Road width
Fdim: Dimming factor
Em: Illuminance
T: Time (h)
η: Luminaire efficacy

M: Fitting factor:
- M = 1.3 for existing lighting systems where positions of existing light points and poles cannot be changed
- M = 1.2 for new lighting systems

Two different fitting factors M = 1.2 or 1.3 are used depending on whether the complete lighting system is newly installed (position of poles and luminaires can be selected) or already existing poles are used.

4.4.1.3 Power factor
The relevance of the power factor for the overall energy related performance of lighting systems is explained in chapter 2. For PremiumLight-Pro two different requirements are recommended covering the power factor at full load and in dimmed situation at 50 % load.

PremiumLight-Pro-Requirement:
Power factor at full load: cos phi ≥ 0.9

For dimmable systems: Power factor at 50 % load:
cos phi ≥ 0.8

Verification
The tenderer shall specify and confirm the power factor in the technical documentation of the tender. The power factor shall be reported according to the relevant ecodesign legislation and related relevant standards.

4.4.2 Quality and design criteria

4.4.2.1 Light colour, colour rendering and colour consistency

Colour temperature (light colour)
For the selection of the light colour (colour temperature) the road type, i.e. the specific area of application has to be considered. Light colour for street lighting involves different colour temperatures for different areas of application mostly (most commonly between 3000 K and 4000 K). Research has shown that white light supports the perception of the human eye more effectively than yellowish light. White light appears as being brighter compared to yellowish white. For more details on colour temperature see chapter 2 (pp10).

Due to different needs no standard requirement for light colour can be specified but the selection of the colour temperature depends on the area of application and different preferences. PremiumLight-Pro therefore provides only general recommendations.

PremiumLight-Pro recommendation:
- Colour temperature for domestic areas and mainly pedestrian areas is recommended to be approximately 3000 K
- Colour temperature for main roads, motorways and areas with mixed traffic is recommended to be approximately 4000 K

Colour rendering

Besides colour temperature, colour rendering is also of importance for the perception of objects and different colours. Again, it is not feasible to make strict requirements concerning colour rendering but recommendations can be given.

PremiumLight-Pro recommendation:
- Colour rendering (CRI) shall be better than Ra 70 (Ra ≥ 70) for motorways and main roads
- Colour rendering shall be better than Ra 80 (Ra ≥ 80) for roads with complex user situations including mixed traffic, cyclists and pedestrians

Colour consistency and maintenance

The colour consistency specifies the deviation of the light colour from the standard light colour (specific point in the colour coordinate system). The maintenance of the colour consistency describes the deviation of the colour over time. Both deviations are specified by MacAdam ellipses (for details see chapter 2).

PremiumLight-Pro requirement
- The colour consistency of the light source or luminaire at the time the system is put into operation shall be within 5 a five step MacAdam ellipse
- The colour consistency of the light source or luminaire over the luminaire lifetime shall be within a 6 step MacAdam ellipse

Verification

The tenderer shall specify and confirm the parameters in the technical documentation of the tender. Parameters shall be declared according to the appropriate standards and legislation.

4.4.2.2 Luminance and illuminance

The luminance and illuminance levels shall be specified according to the needs for the specific road types and shall follow the requirements specified in EN 13201.

PremiumLight-Pro requirement
- Illuminance shall be specified according to the requirements in standard EN 13201
- Luminance shall be specified according to the requirements in standard EN 13201

4.4.2.3 Light pollution

Light pollution is defined as light emission which does not support the specific lighting task but spreads to areas where lighting is undesirable (e. g. night sky, houses etc. see page 10). As explained in chapter 2, light pollution should be avoided as much as possible by appropriate design. Undesired lighting of the environment reduces efficiency and may have negative effects both on humans, birds and animals.

The most important indicator for light pollution is the upward light output ratio (ULOR) which is the amount of light emitted above the horizontal plane at the position of the luminaire.

PremiumLight-Pro requirement
- The upward light output ratio ULOR of the luminaire shall be 0% for all road classes and lighting situations where no other values are explicitly desirable.

As a result unnecessary light pollution is avoided. LED technology in general allows for a more precise light distribution and therefore a reduction of light pollution. Requirements for ULOR among others have been specified in the technical guide CIE 126:1997.

For traditional HID cobra-head luminaires there was a trade-off between drop refractor type lenses and flat glass lenses. Today for LED lighting systems only flat glass units are recommended which allow more precise and efficient light distribution. Flat glass units usually have less upward light output, better control of light trespass into residential windows, and lower high angle glare.

Verification

The tenderer shall provide the photometric file which must include information on the upward light output ratio.

4.4.2.4 Glare protection

Glare is an important quality parameter for street lighting as it directly affects safety and comfort. For both disability glare and discomfort glare a standard classification of different glare levels is available (for definitions see chapter 2). For both parameters 6 classes are currently defined (G1-G6 for disability glare, D1-D6 for discomfort glare).

PremiumLight-Pro-Requirement:
- For disability glare it is recommended to use products with a shield class of minimum G4 or higher. In general, systems with a plain shield shall be used.
- Concerning discomfort glare it is recommended to use products with a glare class of D6 for local roads and residential areas. For pedestrian streets a glare class of D5 is recommend.
- Similar levels for glare class are recommended by some national and international guidelines (e.g. Danish guidelines on street lighting).

Verification
The glare class of products is to be specified by the tenderer.

4.4.2.5 Protection requirements for luminaires

Ingress protection
Light quality and lumen output is affected by the amount of dirt and water infiltrating the luminaire. Thus the luminaire shall provide sufficient ingress protection which is specified by the IP rating (according to CIE 154:2003). The IP rating is also relevant for the luminaire maintenance factor. The Ecodesign Regulation EC/245/2009 indicates IP65 as a benchmark for the road classes ME1 to ME6 and MEW1 to MEW6. (IP65: No ingress of dust, complete protection against contact and water projection covering all typical weather conditions).

PremiumLight-Pro requirement:
- For ingress protection IP 65 shall be applied for all road classes.

Impact protection
Different impact rating classes are typically used for different road types and situations. E.g. in Denmark impact protection classes between IK06 and IK10 are applied [VEJ].

PremiumLight-Pro requirement:
- The luminaire shall have an impact protection rating greater than IK07.

Verification
All requirements at the luminaire level shall be confirmed with appropriate product information and relevant declarations according to EU regulations and standards by the tenderer.

Electrical protection (IEC)
Electrical protection ensures sufficient insulation of parts in case of failure.

PremiumLight-Pro requirement:
- All luminaires shall have Class II electrical protection.

This ensures that there are two layers of insulation that offer protection from live parts in case of failure. Class II protection is quite common and recommended for lighting installations [e.g. WB and VEJ].

Overvoltage protection (IEC)
Overvoltage protection ensures protection against damages from high voltage.

PremiumLight-Pro requirement:
- The installation shall have overvoltage protection of 10 kV

This ensures that the lamp has protection against all but the most extreme transient overvoltage. Overvoltage protection of > 4 kV is commonly applied [SES]. The proposed level is more tentative.

Verification
The voltage level and overvoltage protection is to be declared by the tenderer.

4.4.3 Mark of conformity

Marks of conformity ensure that the lighting system components comply with the essential standards for electrical products. In any case, CE marking is mandatory for products sold in the EU and therefore not explicitly mentioned as a special requirement.

PremiumLight-Pro-Requirement:
All components of the lighting system shall have the following marks of conformity:
- ENEC (European Norm Electromechanical Certification)

Verification
The tenderer shall provide a declaration of conformity for all relevant components.

4.4.3.1 Lifetime, warranty and reparability

Luminaire and led module Lifetime

The minimum luminaire lifetime is specified as LxBy requirement (see chapter 2). For PremiumLight-Pro it is assumed that the lifetime is declared as a L80B10 value.

PremiumLight-Pro requirement:

- The luminaire shall have a rated lifetime of at least L80B10 = 100,000 h.

PremiumLight-Pro criteria cover LED technology only. Thus lifetime requirements appropriate e. g. for high pressure discharge lamps are not considered. The guidelines by topstreetlight.ch for example recommend an LED luminaire lifetime of at least 100,000 h. [SES]

Verification

The tenderer shall provide the technical specifications of the luminaire (which are based on state-of-the-art measurement methods including, where available, harmonised European standards).

Life time of control gear

Control gear (drivers) are a common source of failure and thus significantly affect the need for maintenance and repair. High quality control gear allows a lifetime of 100,000 h, whereas lower quality products may reach only 30,000 h or even less.

PremiumLight-Pro requirement:

The failure rate of the control gear shall be lower than 0.1 % per 1.000 hours. Failure after 100.000 h shall be lower than 10 %.

Verification

The tenderer shall provide the technical specifications of the control gear (based on recognised state-of-the-art measurement methods including, where available, harmonised European standards)

Warranty

The warranty for the lighting system (covering individual components of the system as well as reparability) is an essential feature supporting the expected lifetime of the lighting installation. Long lifetime may justify higher initial investment for more efficient high quality LED street lighting installations.

Overall repair and maintenance should be possible without proprietary equipment.

PremiumLight-Pro requirement:

The warranty and/or service agreement period shall cover a minimum ten years and include:

a Replacement of defective light sources (including decrease of lumens below specified levels), control gear and/or luminaire at no cost.

b Complete replacement of batches of luminaires in case more than 10 % of the units in the batch are defective.

The warranty should exclude the following cases:

c Luminaires defective because of vandalism, accidents, or due to adverse weather effects.

d Lamps and luminaires operated under abnormal conditions (e. g. used with the wrong line voltage)

Reparability and availability of spare parts

PremiumLight-Pro requirement:

- The availability of spare parts shall be guaranteed for a period of ten years. Concerning reparability, the light source (lamp or LED module) and auxiliaries must be easily accessible and replaceable on site (i.e. at luminaire mounting height). Repair shall be accomplishable with standard, widely accessible tools.

Certain communities request even more extended availability for spare parts, for example 15 years.

A current design trend is for LED modules that are completely integrated in the luminaire and therefore cannot be replaced by new modules. However in light of current circular economy strategies and strategies supporting longer product lifetime, replaceability of LED modules should be mandatory.

Verification

The warranty or service agreement shall be specified in the tender indicating the parts which are covered by the service agreements and the guarantee. A spare part list shall be provided together with a manual and diagram of the luminaire illustrating access, demounting and mounting of parts.

4.4.4 Life Cycle Costs/TCO

The economy of new LED lighting systems is best assessed by a life cycle costing approach. While the purchasing costs may be higher compared to traditional lighting systems, total costs including operation and maintenance often are lower. A life cycle or TCO assessment approach may allow more "costly" solutions in terms of initial investment which are more cost efficient over the systems lifetime.

PremiumLight-Pro-Requirement:
The tenderer shall calculate the life cycle cost (TCO) for the street lighting installation using a method specified by the procurer. For example one of the following approaches could be applied:
- The present value method as specified by the CIE 115:2010 Technical Report, p. 24. [CIE]
- The average annual costs method as specified by the CIE 115:2010 Technical Report, p. 24. [CIE]
- The method specified by Requirement ID:10677:1 of the Swedish National Agency for Public Procurement (Uphandlings myndigheten) [UM]

TCO calculations shall include parameters such as cost of labour, electricity costs, purchase price, expected lifetime of luminaires, maintenance costs (time to clean a luminaire in group cleaning, time to repair a luminaire in spot replacement, frequency for luminaire cleaning, etc.).

Verification
The tenderers shall provide an LCC/TCO calculation based on an accepted cost calculation method which shall be specified by the procurer.

4.4.5 Contractual issues

Several requirements to be considered in the tender are not technical requirements to be used for the tender assessment but belong to the contractual specifications.

Correct installation of the lighting system is a basic requirement ensuring safe and efficient operation. Therefore procurement criteria should include installation requirements and information and documentation for maintenance.

4.4.5.1 Correct installation and calibration
In order to ensure adequate illumination levels and lighting quality in line with the relevant standards, correct installation of the lighting system is essential. The following requirements ensure that the lighting system installed complies with the relevant specifications and standards.

Correct installation
PremiumLight-Pro Requirement:
The tenderer shall:
- ensure that all lighting equipment (including lamps, luminaires, lighting controls and metering systems) is installed exactly as specified in the design.
- provide documentation of all installed lighting equipment confirming that the equipment complies with the original specifications.
- conduct measurements for a randomly selected road segment that certify the compliance of the lighting system with the specifications and relevant standards. Among others the PDI and AECI shall be calculated based on measurements for one week according to EN 13201 (calculation with a tolerance of +/-10%).
- verify the criteria for light pollution by measurement of the boom angle for a set of randomly selected luminaires (+/- 2° tolerance max.).

Verification
The tenderer shall provide all specified documents and results from measurements.

Calibration
PremiumLight-Pro Requirement:
The tenderer shall ensure that the lighting system controls work as specified and energy consumption is not higher than specified in the lighting system design. In particular, it shall be verified that the following types of control features are calibrated and operate correctly:
- Daylight-sensitive control systems
- Traffic based control
- Time switches

Verification
The contractor shall adjust the system according to the requirements and specifications and provide the related documentation. Furthermore, the tenderer shall provide all relevant information and documentation which is required for the operation and maintenance of the control features.

Information and documentation concerning maintenance, replacement and recalibration
PremiumLight-Pro Requirement:
Comprehensive documentation shall ensure that the operator of the lighting system is equipped with all relevant information required for efficient operation and maintenance. The tenderer shall provide the following information:
- Disassembly instructions for luminaires
- Instructions on replacement of light sources (types and procedures)

- Instructions on operation and recalibration of lighting controls and adjustment of switch-off times

Verification
The tenderer provides all relevant documentation as well as instruction for the responsible staff.

4.4.6 Reduction of waste and recovery of materials

Reduction of waste and recovery of raw materials is essential for the majority of street lighting installations as most newly installed systems replace old systems. Substantial amounts of waste are to be collected and various materials can be recovered.

PremiumLight-Pro Requirement:
During dismounting and new installation all relevant components shall be separated and recovered in accordance with the WEEE Directive (Directive on Waste Electrical & Electronic Equipment) of the European Union. [WEE].

Verification
The tenderer shall declare how the waste will be separated and materials will be recovered during dismounting of the old system and installation of the new system.

4.5 PremiumLight-Pro award criteria – weighting and score

4.5.1 Introduction

In the previous section both mandatory minimum criteria and award criteria are specified. For the award criteria also listed in table 12 a score is applied which allows ranking of tender offers. For the calculation of the total score a weighting of different types of criteria is required. The following section provides a proposal for a possible weighting concept.

Tables 12 and 13 show the proposed weighting for the award criteria. The two approaches show concepts for projects with and without TCO calculation.

For projects where a robust TCO approach can be applied covering the main parameters concerning investment-, operation and maintenance costs only few additional parameters including quality, design, warranty and end of life aspects need to be covered (see table 12). Energy consumption and maintenance is already covered in the electricity and maintenance costs. Consequently the weight of the TCO criteria is comparably high.

In cases where TCO is not assessed energy, maintenance costs and investment costs are assessed separately.

The weighting of criteria typically is adapted to local needs. Thus the proposed weighting presented here is just to be seen as one possible option.

Table 12 *The proposed weighting for Award criteria For Projects Including TCO information*

Award criterion		Weighting [%]
Cost criteria based on total cost of ownership (TCO)		50
TCO	Investment costs	15
	Electricity costs	20
	Maintenance costs	15
Quality and design criteria		30
Lighting Quality		20
Design		10
Warranty, Design for Recycling		20
Warranty		10
Availability of spare parts, Design for Recycling		10
Total		100

Table 13 *Weighting for Award criteria For Projects excluding TCO information*

Award criterion	Weighting [%]
Cost criteria	25
Investment costs	25
Quality and design criteria	35
Lighting Quality and Lifetime	25
Design	10
Energy criteria	20
AECI or PDI or component efficiency (depending on the type of project the most appropriate indicator shall be used; some types of projects only allow for use of PDI or component efficiency)	20
Operation, Maintenance, End of life criteria	20
Ease of maintenance, repair	10
Warranty, availability of spare parts	10
Total	100

Literature

BAT – Bats in the Anthropocene: Conservation of Bats in a Changing World (2016). C. Voigt, T. Kingston (Editors). Springer Open

BFE – Energieeffiziente Straßenbeleuchtung mit LED (2016). Energie Schweiz, BFE

BG – Beleuchtungstechnik Grundlagen (2016). Baer, Barfuß, Seifert. HUSS-MEDIEN GmbH, Berlin

CIE – CIE 115:2010 Technical Report "Lighting of Roads for Motor and Pedestrian Traffic", Commission Internationale De L'Eclairage

European Commission (2015a): Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report Task 3: Use of Light Sources

European Commission (2015b): Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report Task 4: Technologies

EN 13201-1:2014 – Street lighting. Guidelines on selection of lighting classes;

EN 13201-2:2015 – Street lighting – Part 2: Performance requirements;

EN 13201-3:2015 – Street lighting – Part 3: Calculation of performance;

EN 13201-4:2015 – Street lighting – Part 4: Methods of measuring lighting performance;

EN 13201-5:2015 –Street lighting – Part 5: Energy performance indicators;

ENG – Engineering: Progress in Understanding Color Maintenance in Solid-State Lighting Systems (2015). Maryam Yazdan Mehra, Willem Dirk van Driela, G. Q. (Kouchi) Zhang, Volume 1, Issue 2, 2015, Pages 170–178

GPP – Revision of the EU Green Public Procurement Criteria for Street Lighting and Traffic Signals (2016); Technical report and criteria proposal (1st draft)

IIEC – International Institute for Energy Conservation (2015): Energy Efficiency Guidelines for Street Lighting in the Pacific; Bankok

LRT – An examination of the fundamentals of street lighting for pedestrians and drivers (2004). P Raynham. Lighting Res. Technol. 36, 4 2004 pp. 307–316

LRT2 – A smart LED luminaire for energy savings in pedestrian street lighting (2015). E Juntunen, E Tetri, O Tapaninen, S Yrjänä, V Kondratyev, A Sitomaniemi, H Siirtola, EM Sarjanoja, J Aikio, V Heikkinen. Lighting Res. Technol. 2015; Vol. 47: 103–115

PE – The design and implementation of an energy efficient street lighting monitoring and control system (2012). Electrical Review, ISSN 0033-2097, R. 88 NR 11a

RO – Lighting (2014).D.C. Pritchard. Routledge

RL – Street lighting (2015): Fundamentals, Technology, and Application. Wout van Bommel, Springer

SdN – Schutz der Nacht – Lichtverschmutzung, Biodiversität und Nachtlandschaft (2013). BfN-Skripten 336, Bundesamt für Naturschutz, M. Held, F. Hölker, B. Jessel (Editors)

SEN – Streetlight Control System Based on Wireless Communication over DALI Protocol (2016). F J Bellido-Outeiriño, F JQuiles-Latorre, C D Moreno-Moreno, PMC

SES – Straßenbeleuchtung (2016). Effiziente Systeme – Empfehlungen für Gemeindebehörden und Beleuchtungsbetreiber. topstreetlight.ch

VEJ – Handbook Street Lighting – Construction and Planning (2015). Vejregler, Denmark

WEEE – Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)

ZHA – Zhaga Interface specification book 1 (2015): overview and common information, Edition 1.7

ZHA5 – Zhaga Interface Specification Book 5 (2014): Socketable LED Light Engine with Separate Electronic Control Gear, Edition 1.2

ZVEI – Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (2016): Leitfanden Planungssicherheit in der LED-Beleuchtung Begriffe, Definitionen und Messverfahren: Grundlagen für Vergleichbarkeit, Frankfurt am Main

ZVEI2 – Überspannungsfestigkeit in Leuchten der Schutzklasse II für die Straßenbeleuchtung (2014). Informationspapier, Zentralverband Elektrotechnik- und Elektronikindustrie

ZVEI3 – Information zum Dimmen von LED-Lichtquellen (2014). ZVEI – Zentralverband Elektrotechnik und Elektronikindustrie e.V., 2014

PremiumLight-Pro Consortium:

Austria
Austrian Energy Agency
www.energyagency.at

Czech Republic
SEVEn, The Energy Efficiency Center
www.svn.cz

Denmark
Energy piano

Portugal
Institute for Systems and Robotics,
University of Coimbra

United Kingdom
Energy Saving Trust
www.energysavingtrust.org.uk

Germany
co2online gGmbH
www.co2online.de

Italy
Politecnico Milano
www.energia.polimi.it

Spain
Ecoserveis
www.ecoserveis.net

Poland
FEWE, Polish Foundation for Energy
Efficiency, www.fewe.pl

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