SMARTLIGHT STREET& URBAN

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Artificial lighting is arguably the most important aspect of the night landscape as it facilitates visual acuity in an environment that would otherwise be treacherous to navigate.

Therefore, the illumination of our streets and urban spaces is fundamental to our safety as well as our visual and psychological comfort during the darker hours. Such illumination demands much from a lighting system, making it necessary to bear in mind a great many factors and to draw on a wealth of experience and knowledge. Furthermore, if developed by capable hands, street and urban lighting can do so much more than act as the medium of that all-important illumination. It can also transform the aesthetic appearance of streets, squares, pathways, bridges and parks, and bring a new lease of life to our night landscape.

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CONTENT

LIGHT & SAFETY

A new way of thinking about the safety, security and efficiency of our streets.

Street and urban lighting systems need no longer be defined by the yellow light of high-pressure sodium lamps, which were chosen purely based on their efficacy. Now there is another option, one that is simply better.

Advancements in light source technology now allow us to introduce a new light to our streets and urban spaces, a light that combines properties of daylight with energy efficiency. That light is high quality white light, which is perceived as brighter and more natural than the light emitted by conventional light sources. White light sources have comparable or better efficacies than high-pressure sodium lamps, with another benefit being that the light emitted is more visually effective.

Current standards for street and urban lighting, with a focus especially on the illumination of roads, do not fully implement the findings of modern research and understanding of light. In order to achieve the greatest energy savings, it is important that all involved in the creation of standards and the manufacture of luminaires and light sources use the available knowledge to make our streets safer and more efficient.

WHITE LIGHT

The yellow light of many older streetlighting luminaires enables very poor colour rendition, which limits visual acuity. Another disadvantage is that the light is emitted in all directions, including into the night sky, causing light pollution. White light, in combination with modern luminaires, ensures that the light is emitted onto the roads and pavements and not wasted where it is not needed. This minimises light pollution and helps to reduce the incidence of traffic accidents as well as criminal activity, making our streets and urban spaces look better and feel safer.

Security, crime and accident prevention

The main function of street and urban lighting in the darker hours is to provide high enough levels of illumination to enable the detection and identification of objects and people, as well as escape routes in the event of an emergency. There is clear quantitative evidence suggesting that vertical illumination at a level of 10–30 lx enables those whose vision is fully adapted to the light level to easily detect and recognise objects and approaching people, cyclists and vehicles.

Another function of street and urban lighting is property protection. The most commonly used security lighting technique involves illuminating a guarded area with at least twice as much light as adjoining areas. This enables easy recognition of any activity in the area as well as reducing shadows and dark corners where criminals could lurk. An alternative technique could be to illuminate only key areas using luminaires directed outwards to brightly illuminate such weak spots as entrances and deter criminals from attempting to break in or damage property. Furthermore, street and urban lighting also enables CCTV cameras to clearly record the events in monitored locations.

White light is highly beneficial with regard to all the demands placed on street and urban lighting as it is perceived as brighter and provides superior colour rendition compared to the yellow light so commonly found. This greatly improves the visual acuity of those in our streets and urban spaces, encouraging people to enter areas and stay longer, which in turn acts to invite more people, ultimately leading to increased safety and security. In addition, white light also improves the clarity of images recorded by CCTV cameras, helping in the identification of people and vehicles as well as providing reliable evidence in the case of recorded criminal activity.

These two photographs show similar streets. On the left is a street illuminated by an old lighting installation, and on the right, another street after the lighting was renovated using modern luminaires and white light sources.

The white light is more focused where needed and appears brighter and more natural, promoting safety. The new installation is also much more efficient.

White light enables the police to better guard our streets.

With white light, it is easier to identify criminals.

Safety and atmosphere

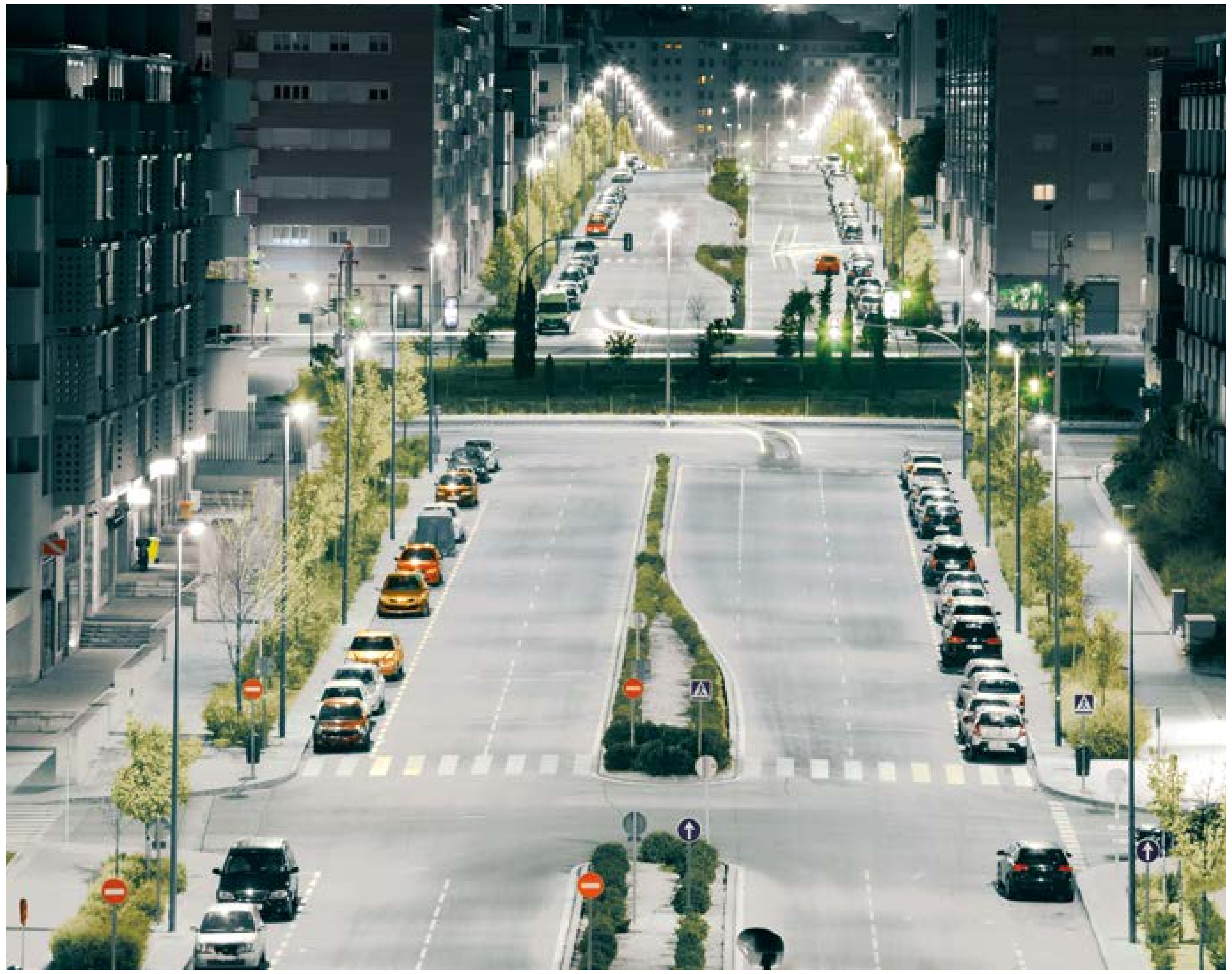
It goes without saying that better visibility improves road safety. White light enables higher levels of peripheral visual acuity, helping drivers to notice roadside movement sooner and from a greater distance. This gives them precious extra time to stop in the case that a child, pedestrian, cyclist or animal unexpectedly crosses their path, reducing the incidence of accidents and fatalities.

Increased visibility is just as beneficial to pedestrians as for road users, helping them to see and react to oncoming traffic sooner. There is also evidence that higher levels of visual acuity act to prevent pedestrian accidents as obstacles are more clearly seen and avoided.

White light is ideal for the illumination of streets and urban areas not only because of its ability to improve visual acuity, but also thanks to the ambience it creates. The properties of white light are similar to those of daylight, making it preferred over the unnatural yellow glow of high-pressure sodium lamps. The natural atmosphere created by white light promotes feelings of safety, making our public spaces more livable and enjoyable.

White light is also perfect for illuminating architectural areas as it highlights details that would normally be lost during the night hours. People react positively to the new life this breathes into parks, city squares and streets, encouraging them to spend more time celebrating the beauty of their towns and cities and instilling feelings of civic pride.

From a practical point of view, by encouraging increased activity in public areas, white light also indirectly improves safety and security as increased numbers of people automatically make a space safer. It discourages criminal activity such as vandalism and aggressive behaviour and in turn makes it even more appealing for residents to spend time outside. The effects support and strengthen each other, bringing a whole new lease of life to our hometowns.



White light enables higher levels of visual acuity for pedestrians and road users, reducing the incidence of accidents.

Aesthetics and development

Well designed street and urban lighting can support the economy of communities and cities by attracting visitors to all matter of outdoor activities such as markets, concerts and cultural events. It is, therefore, important that key buildings, monuments and parks are well illuminated to be appealing to those passing through.

Higher levels of illumination should always be used for paths, signs, building facades and landscape features. The choice of light colour and the ability of a light source to render colours well should be key factors in a lighting designer's concept.

Visibility and comfort

Visual acuity is determined by brightness level, lighting uniformity and distribution, contrast and glare. It is important that street and urban lighting be designed to illuminate areas as uniformly as possible so as to minimise the need for our eyes to adapt to changes in brightness. It is also vital to maintain sufficient levels of contrast between objects and their background to aid perception and recognition. However, visually detrimental excessive contrasts should be avoided at all times.

Contrast is defined by calculating the difference between the luminance of an object and its background. The illumination level need not be enough to enable easy perception of colour or detail. The contrast provided by white light makes it easier to identify objects as well as increasing the perception of colour and detail. This leads to safer roads for all users and pedestrians as they can more clearly see what is happening around them.

Our homes and communities feel safer and are more secure with the right lighting.

City centres can feel bright and airy even during the night.

The details of architectural buildings and monuments need no longer be lost in darkness.

Uniform illumination improves visual acuity.

ENERGY SAVING POTENTIAL

In modern streetlighting installations, there exist ways by which to save significant amounts of energy while guaranteeing that the provided light is of an appropriate quality and quantity for the given road conditions in accordance with standards.

One way is through the use of a Lighting Management System (LMS) that regulates the lighting according to estimated or real-time traffic flow, and/or according to real-time weather conditions. In both cases, it is possible to achieve this energy saving based on the idea that when the illumination of a road exceeds that defined by standards for the given conditions, it is possible for the LMS to reduce the output accordingly without it falling below standard or compromising road safety. This functionality can be supplemented by the Constant Lumen Output feature programmed into many LED drivers, which compensates for the inherent lumen decrease of light sources throughout their lifetime.

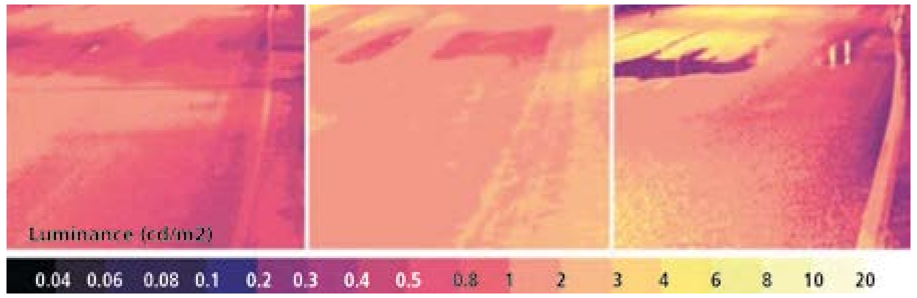
A further energy saving method involves the use of light sources with high S/P ratios, which emit higher quality light that provides the same level of visual acuity from less energy when compared to conventional light sources with lower S/P ratios. Furthermore, the use of high performance optics can improve energy saving potential due to the luminous output being better distributed and losses minimised. In order to benefit from these energy saving methods, the luminaire design must be factored into the overall system design from the beginning of the planning process.

Each of the mentioned methods can be used independently or in connection with others. In all cases, we can rest assured that at no point will the road illumination be insufficient, and that savings are always possible.

Traffic flow

The required lighting parameters for one road can vary greatly depending on traffic flow, especially in terms of required luminance levels. When traffic flow is lighter, predominantly during the early morning hours, it can be appropriate to reduce levels of luminance without compromising safety. It is necessary to classify the road for every reference point of time according to the tables found in Annex A of EN 13201-1 and in accordance with the appropriate road authorities. However, standards only classify traffic flow according to the number of cars using a road per day, not taking into consideration rush hours and times of little activity. In this case it is necessary to use a little common sense to identify the times when traffic flow is greater or lesser and to adapt the road lighting requirements accordingly.

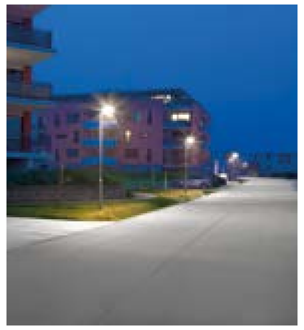
It is necessary to use dynamic road lighting to achieve the desired reduction in illumination according to traffic flow, as well as according to the time of day and weather conditions. However, it is possible to use a common LMS to adapt lighting conditions to expected traffic flow and times of day even if not according to weather conditions, an option that is easy to implement and still provides significant saving potential.



Luminance distribution of an observed MEW3 class road in different weather conditions.

European standard EN 13201-2 requirements for the illumination of MEW3 class roads	
L_{av} = 1 cd/m²	
U_0 = 0.4	Dry conditions
U_0 = 0.15	Wet conditions
U_l = 0.6	The application of the criterion is voluntary but recommended for high class roads and motorways

Luminance and lighting uniformity requirements for MEW3 class roads.



Dry surface
L_{av} = 1.11 cd/m²
U_0 = 0.74
$U_{l,\ left}$ = 0.782
$U_{l,\ right}$ = 0.814

The luminance of an observed road in dry weather conditions. In this case, all recommended photometric parameters are fulfilled. The luminance level is slightly higher than required due to planned over-dimensioning of the system to compensate for deterioration of light output as the lighting system gets dirty and ages.

Slightly snowy surface	
L_{av} = 1.66 cd/m²	49 % higher than in dry weather conditions
U_0 = 0.639	14 % lower than in dry weather conditions
$U_{l,\ left}$ = 0.808	3 % higher than in dry weather conditions
$U_{l,\ right}$ = 0.756	7 % lower than in dry weather conditions

The luminance of an observed road in slightly snowy conditions. In this case, all recommended photometric parameters are fulfilled but the values are not optimal. The average road surface luminance is 49 % higher than in dry weather conditions.

Wet surface	
L_{av} = 2.37 cd/m²	113 % higher than in dry weather conditions
U_0 = 0.22	71 % lower than in dry weather conditions
$U_{l,\ left}$ = 0.398	50 % lower than in dry weather conditions
$U_{l,\ right}$ = 0.618	24 % lower than in dry weather conditions

The luminance of an observed road in wet weather conditions. In this case, recommended photometric parameters are fulfilled with the exception of longitudinal uniformity, the criteria of which is for voluntary application. The average road surface luminance is 113 % higher than in dry weather conditions and the overall uniformity has decreased by 71 % but still fulfils standards.

Weather conditions

The photometric parameters recommended for lighting a road strongly depend on the reflectivity of its surface, which, along with the performance of the lighting installation, is greatly influenced by the prevailing weather conditions at any given time.

What these findings show us is that weather conditions can have a significant impact on the luminance of a road surface. As the human eye registers luminance and not illuminance, it means in practice that lighting levels can be greatly decreased in certain weather conditions while still fulfilling the recommended visual needs of road users. This converts into a considerable potential to save energy when weather conditions are factored into road lighting. It is possible to also apply this kind of energy saving in lighting installations used on ME class roads in drier countries where roads are not often damp or wet during the night hours. However, as energy savings depend on weather conditions, the overall saving potential will be less.

S/P ratios and mesopic vision

Further energy savings can be provided by using light sources with high S/P ratios – the ratio between scotopic and photopic vision. This is based on understanding and utilising the basic physiology of the human eye and its receptors. There are three types of receptor, two of which are responsible for basic vision. Cones are most active in well-lit conditions and therefore act as the base for photopic vision. Rods are most active in poorly-lit conditions and therefore act as the base for scotopic vision. Mesopic vision lays somewhere between photopic and scotopic vision and is facilitated by both cones and rods. Cones and rods have increased sensitivity to different parts of the light spectrum. In darker conditions, our vision is more acute under light that is strong in lower wavelengths (green/blue) and less acute under light that is strong in higher wavelengths (yellow/red). By taking advantage of this we can provide light that is literally more effective at a given brightness level. For example, under the light emitted by a high-pressure sodium lamp the S/P ratio is a very low 0.65 with brightness perception reduced by 35 % in scotopic conditions when compared to photopic conditions. The table (above right) compares mesopic with photopic vision at various luminances and using different light sources with different S/P ratios.

	Luminance
Photopic vision	>5 cd/m²
Mesopic vision	0.005–5 cd/m²
Scotopic vision	<0.005 cd/m²
Used luminance on road	0.3–2 cd/m²

Vision types and luminance.

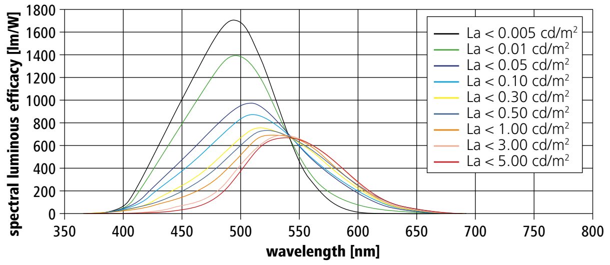
Light source	S/P	Photopic luminance [cd/m²]									
		0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
LPS~	0.25	-75 %	-52 %	-29 %	-18 %	-14 %	-9 %	-6 %	-5 %	-2 %	0 %
HPS~	0.45	-55 %	-34 %	-21 %	-13 %	-10 %	-6 %	-4 %	-3 %	-2 %	0 %
	0.65	-31 %	-20 %	-13 %	-8 %	-6 %	-4 %	-3 %	-2 %	-1 %	0 %
WWMH~	0.85	-12 %	-8 %	-5 %	-3 %	-3 %	-2 %	-1 %	-1 %	0 %	0 %
	1.05	4 %	3 %	2 %	1 %	1 %	1 %	0 %	0 %	0 %	0 %
	1.25	18 %	13 %	8 %	5 %	4 %	3 %	2 %	1 %	1 %	0 %
	1.45	32 %	22 %	15 %	9 %	7 %	5 %	3 %	3 %	1 %	0 %
	1.65	45 %	32 %	21 %	13 %	10 %	7 %	5 %	4 %	2 %	0 %
	1.85	57 %	40 %	27 %	17 %	13 %	9 %	6 %	5 %	3 %	0 %
	2.05	69 %	49 %	32 %	21 %	16 %	11 %	8 %	6 %	3 %	0 %
CWLED~	2.25	80 %	57 %	38 %	24 %	19 %	12 %	9 %	7 %	4 %	0 %
CWMH~	2.45	91 %	65 %	43 %	28 %	22 %	14 %	10 %	8 %	4 %	0 %
	2.65	101 %	73 %	49 %	31 %	24 %	16 %	12 %	9 %	5 %	0 %

Differences between mesopic and photopic luminance (%) calculated with the recommended mesopic system for a range of light source S/P ratios (CIE 191).

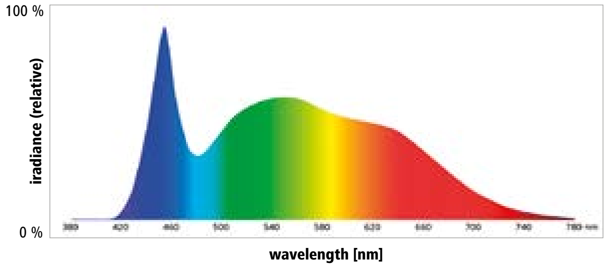
Light source	S/P ratio
Incandescent	1.36
Fluorescent (3500 K)	1.36
Fluorescent (5000 K)	1.97
Metal-halide (warm white)	1.20
Metal-halide (cool white)	2.4
High-pressure sodium	0.65
Low-pressure sodium	0.25
LED (3500 K)	1.39
LED (6000 K)	2.18

Examples of the S/P ratios of various light sources.

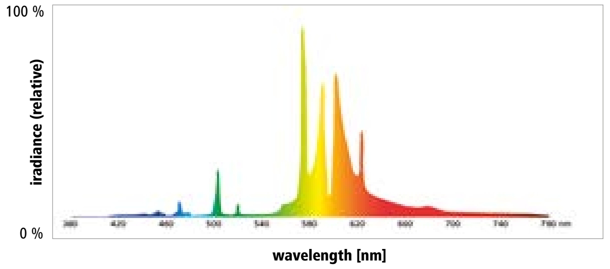
A real example: ME3 class roads are required by standards to have a luminance of 1 cd/m². Compared with photopic conditions, in mesopic conditions we perceive 4 % less light from a high-pressure sodium lamp and 11 % more light from a cool white LED light source. This means that the use of the right kind of LED light source for the illumination of such a road translates into a 15 % improvement in perception when compared to the use of conventional yellow light.



Spectral luminous efficacy of radiation for selected luminances.
To have the highest possible S/P ratio and the best visible conditions, the spectrum must be as similar as possible to the above curve.

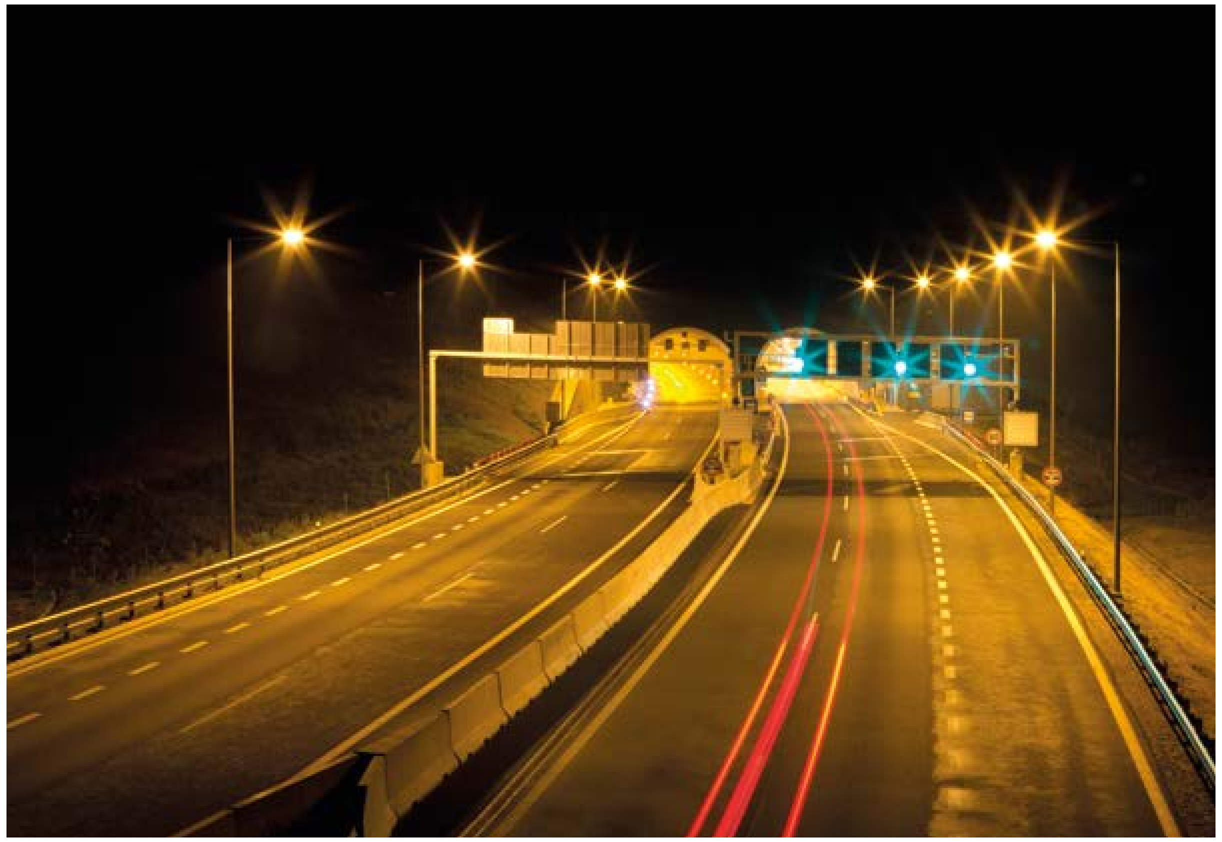


LED 6000 K – S/P = 2.18.



High-pressure sodium – S/P = 0.65.

LED 6000 K – S/P = 2.18.



High-pressure sodium – S/P = 0.65.

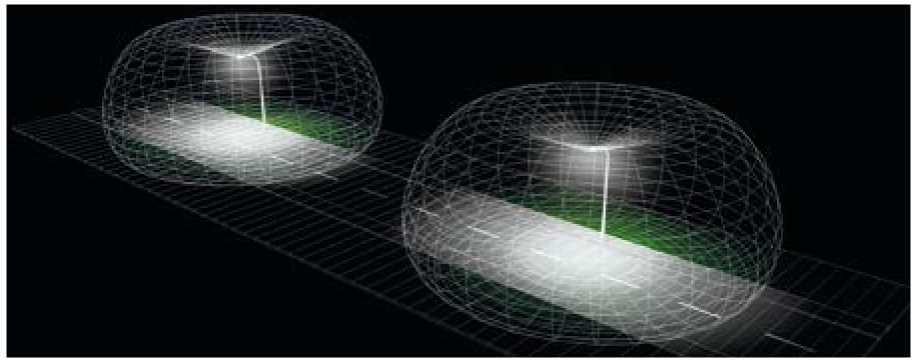
Luminaire optics

Images A and B show how luminaire optics can be developed to minimise the amount of light falling outside of the target area and ensure 100 % illumination uniformity of the road surface. This reduces the amount of light being emitted to where it is not needed, and therefore wasted, which results in a decrease in energy consumption whilst still fulfilling the recommended visual needs of road users. This feature has the added benefit of limiting light pollution.

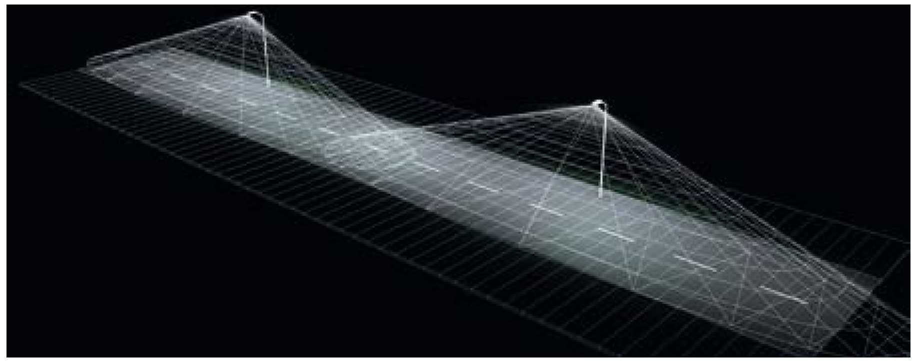
The use of LED light sources for road lighting has several energy saving advantages additional to the positive effect of their S/P ratios. Firstly, they emit light in a direct way as opposed to conventional light sources that emit light in all directions, providing a more effective and therefore efficient distribution of the light falling in the target area. This results in the need for fewer and less powerful light sources to fulfil the recommended visual needs of road users when compared to conventional light sources.

Secondly, they provide more uniform illumination and less glare, which contributes to better visual comfort and acuity for drivers and other road users.

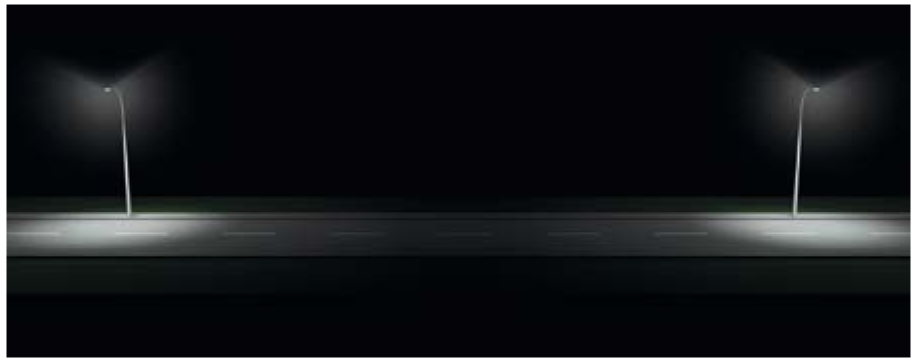
Thirdly, luminaires using high performance optics can laterally project light more then five times the distance of the mounting height, as illustrated in images C and D, for lower class streets, the ratio of height to distance between luminaires can be as high as 1:9. This results in fewer luminaires being needed to fulfil the recommended visual needs of road users, which in turn reduces energy consumption, and installation, labour and maintenance costs.



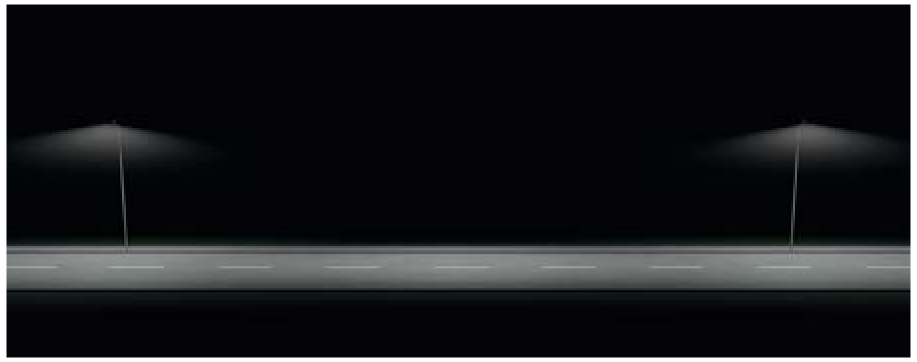
A *Conventional luminaires that allow a large proportion of light to fall outside of the target area and be distributed into the sky as light pollution.*



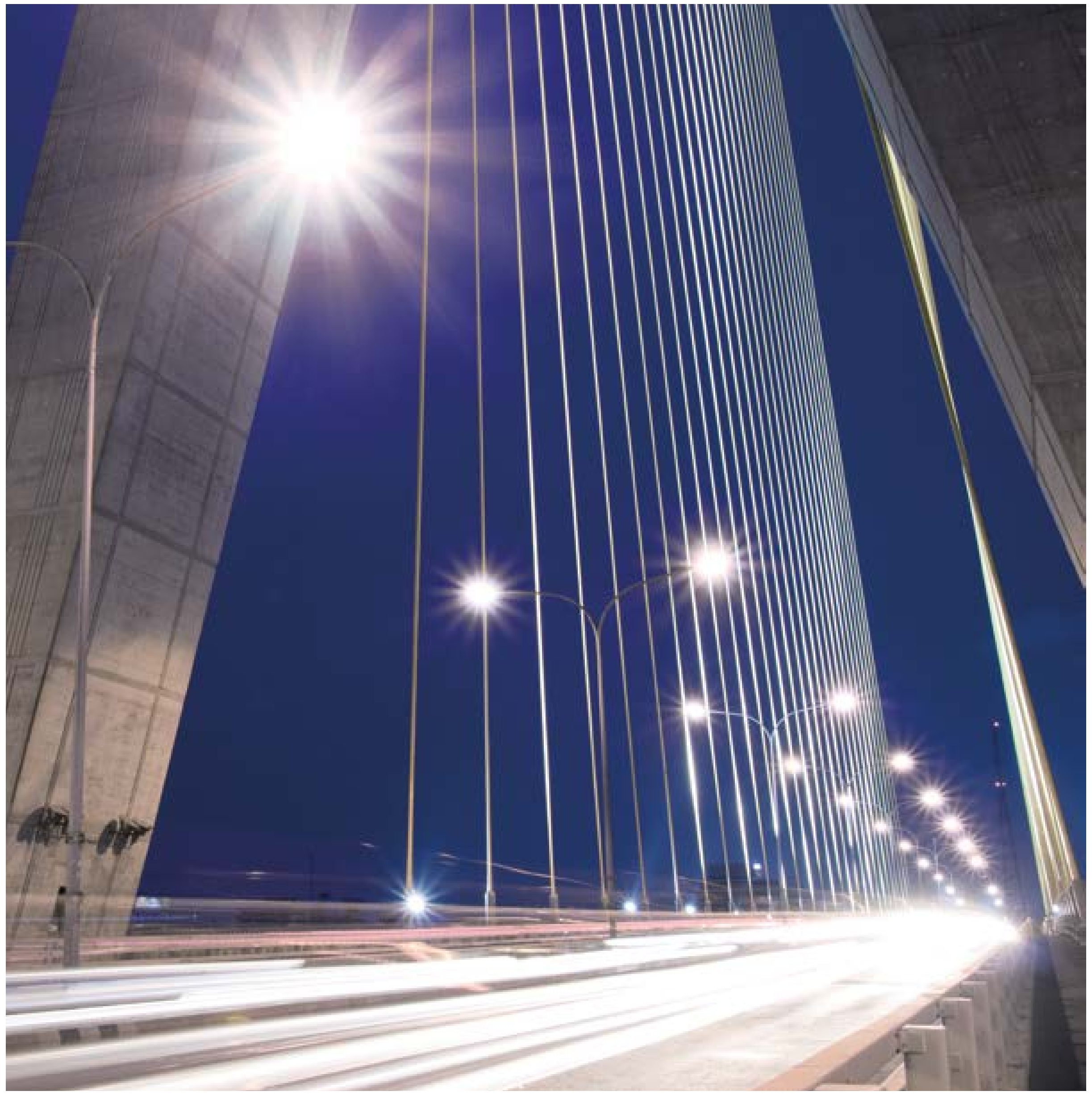
B *Luminaires with high performance optics that minimise the amount of light falling outside of the target area.*



C *Conventional luminaires that illuminate unevenly, creating 'hot spots' that reduce visual acuity.*



D *Luminaires with high performance optics that emit light laterally over a large distance, ensuring that the road is evenly illuminated, and visual acuity maintained.*



The following table shows how much of the light emitted falls in the target area. This is referred to as the Utilisation Factor (UF), calculated by multiplying the average maintained illuminance (lux) by the target area to be illuminated (in m^2), the product of which is divided by the total installed lumens (lm) and multiplied by 100.

We can see from the calculated UF value for the conventional light source luminaire that 46 % of the light emitted is wasted. However, the LED luminaire utilising high performance optics ensures that only 22 % of the emitted light is wasted, an improvement of 24 %. This equates to a 46 % reduction in energy consumption whilst still fulfilling the recommended visual needs of road users.

$$UF = \frac{\text{average maintained illuminance x area of the target illuminated}}{\text{total installed lumens}} \text{ x } 100$$

Light source	Metal-halide 250 W	LED
Net power consumption of luminaire [W]	265	123
Light source power [W]	250	123
Output of the light source [lm]	19,000	10,800
LOR [%]	70.5	85
Net lumen output [lm]	13,400	9,200
Utilisation factor – UF [%]	54	78
Light falling in the target area [lm]	7200	7200

CONCLUSION

The difference between safety and danger is if and how quickly we see potential risk. For this, it is necessary to have the best lighting. No light is more natural for us than daylight. The innovation of LED light sources that emit white light that closely copies the properties of natural light and, therefore, provides improved visual acuity, allows us to reduce the lumen output of a light source while still ensuring the same perceived levels of illumination as a conventional light source that emits very unnatural light.

Effective security lighting enables building occupants to see the forms and faces of those visiting as well as helping the police to secure reliable information and credible evidence by means of CCTV cameras, and to better perform their job in the streets. Furthermore, white lighting actively deters criminal activity thanks to the perceived brightness and the clarity of the illumination.

So, before making a final decision about how best to update your street lighting, be sure to assess the advantages and disadvantages of all available light sources, optics and control systems, to ensure that you fully understand the options and in turn receive the greatest benefits possible.

LIGHT AND US

BRINGING ORDER TO THE LIGHTING WORLD

The development of suitable street and urban lighting depends on the experience, creativity, talent and foresight of those involved, aided by relevant standards and requirements and informed by the results of scientific research and time-tested theories. However, until recently, the combination of these factors was chaotic, and the criteria incomprehensible without due context. At SLE, we believe that high-quality lighting solutions can only be built upon a solid foundation of knowledge and experience and understanding of their application. To achieve this, we saw that the lighting industry required a regulated and systematised lighting assessment methodology that would enable simple, fast, effective and reliable evaluation of lighting solutions. Such a system would not only help lighting designers, planners and engineers, but also customers; supporting them to work together in the creation of truly transformational lighting solutions.

That system is the **Lighting Quality Standard**.

In life, rules are important. When it comes to creating an effective, efficient and safe lighting solution that enables visual acuity and comfort as well as performing a stimulating and emotionally engaging role, there are defined guidelines and parameters to follow. This guidance does not act to limit, but rather to lead and inform the creative and technical processes behind the development of suitable lighting solutions. The Lighting Quality Standard (LQS) forms a logical framework within which both the objective and subjective aspects of a lighting solution can be judged, helping everyone involved in the realisation process stay on track and achieve the best results.

It was not so long ago that every producer of light sources and luminaires had their own system of assessment. It was impossible for customers to judge the quality and suitability of different products, and therefore compare and assess complex solutions. We offer LQS to the lighting world as a tool for all to use and benefit from. It is not merely an aid; it is a significant step forward for the lighting industry.

LQS is comprised of more than twenty objectively quantifiable criteria across six groups, the 6 E's: ERGONOMICS, EMOTION, ECOLOGY, EFFICIENCY, ESPRIT and EXCEPTIONALITY. This framework enables the intuitive assessment and evaluation of everything from individual lighting fixtures to complex lighting solutions. The first four groups are objectively assessable, forming the foundation of the solution. The last two groups are subjective, acting as the 'glue' that completes and perfects the solution. Each category cannot be effectively assessed in isolation from the others, with the best results only achievable when all elements are viewed as a holistic whole. That is the philosophy of LQS, where the structure of the world we live in is crystal clear.

THE KEY IS 6 E's

ERGONOMICS

The delicate and complex interaction of light with the human body.

A sufficient amount of uniform lighting ensures safe navigation of the darkness, making it the master criteria in ergonomic lighting design.

EFFICIENCY

The scientific advancement of lighting and control technologies.

With so many lighting and control possibilities to choose from, an optimum solution can be prepared for every space.

EMOTION

The profound impact light has on emotional response.

Science repeatedly brings to our attention the ability of light to affect mood, perception and performance through the use of physiologically effective light and appropriate illumination techniques.

ESPRIT

The soul of a lighting solution lays in its design and aesthetic value.

Do not underestimate the power of beauty to transform a lighting solution from merely functional to something inspirational.

ECOLOGY

The minimisation of environmental impact related to the illumination of our world.

The ratio of energy converted to light by a light source, in combination with product lifetimes and maintenance costs, are key to making the right lighting choices.

EXCEPTIONALITY

A chain of value that unites and strengthens suppliers, architects, lighting designers, project companies and brands.

A unique vision that combines innovation, global trends, sales and promotion support and the power of mutually beneficial collaboration to create solutions of superior quality and value, and nurture business success.

ERGONOMICS

It is necessary to combine our understanding of all lighting parameters to achieve an effective solution.

The right light, in the right place – that is the ergonomics of light. Yet, what defines the right light? To answer this question, we must understand how light affects the human eye. Only by doing so can we respect the principles that govern our visual world and consequently create a visual harmony that ensures comfort and acuity.

The majority of our understanding of these principles is laid down in the CEN/TR – 13201-1 Technical Report and the EN 13201-2, 3 and 4 European Standards for road lighting. Application of these standards, and where appropriate their surpassing, provides lighting designers with the foundation necessary to choose exactly the right light source, optical system and light distribution for each individual space.

For road lighting applications, standards are justifiably strict and cover many lighting parameters: road surface luminance, illuminance level, lighting uniformity, glare and threshold increment, and surround ratio of illumination. Each parameter must be viewed as part of a holistic whole, ensuring optimum lighting for both drivers and pedestrians.

To adhere to standards and put these lighting parameters into practice, it is essential to know how the road is used: what is its classification, who will use it and what is the typical travel speed of the main user group. Other value specified factors include traffic flow, the presence of parked vehicles, number of junctions, and whether there will be other road users besides those defined as the main user group.

The current standards for Roadway Lighting allow installations to be designed using two methods: the luminance method and the illuminance method. Experienced lighting designers know how to use both methods and can assess the suitability of each for every application.

Class	Road type	
ME / MEW	Roads with motor vehicle traffic travelling at medium to high speeds	
	ME1–ME2	Motorways and high-speed roads
	ME3–ME4	Multi-lane carriageways and important urban roads
	ME5–ME6	Less important roads such as minor and residential roads
CE	Conflict areas with motor vehicle traffic in combination with other road users such as shopping streets, complex junctions, roundabouts and queuing areas	
S / A	Pedestrian and/or bike routes, emergency lanes and those areas separated from the main area of the road in addition to residential roads, pedestrian zones, car parks and schoolyards	
ES	Additionally cover pedestrian areas where there is added focus on crime prevention and minimisation of feelings of insecurity	
EV	Additionally cover areas where there is added focus on the provision of vertical illumination such as at interchange areas	

Road classification.

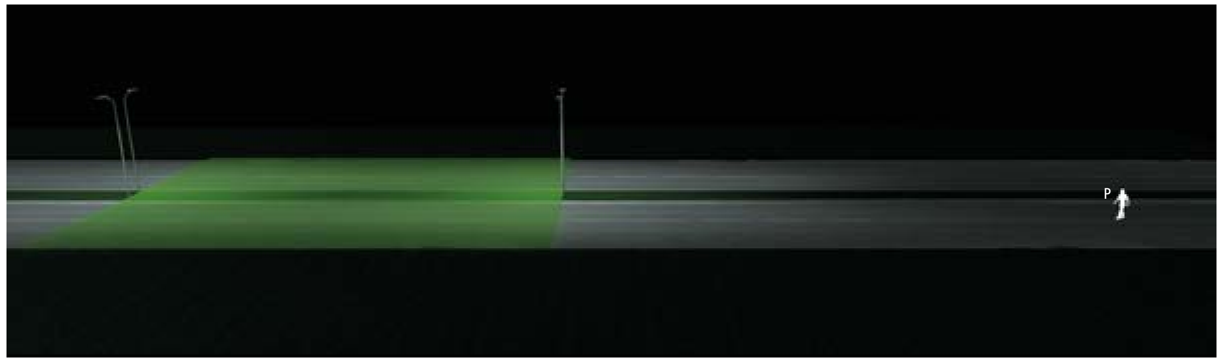
Suitable illumination can only be guaranteed when fundamental illuminance requirements are established.

ROAD SURFACE LUMINANCE

The human eye perceives brightness and the difference between brightness levels. For this reason, luminance is one of the most basic lighting parameters as it expresses most closely the light our eyes actually recognise. Brightness, though, is a subjective attribute of light. For example, a computer screen's brightness can be only adjusted between very dim and bright in a scalable way, usually as a percentage. Luminance, on the other hand, is objectively quantifiable as it is the intensity of light projected onto a given area in a given direction. The unit used to describe luminance is candela per square metre [cd/m²].

The luminance of a road's surface is a key variable when designing the lighting for ME and MEW class roads where traffic travels at moderate (30–60 km/h) and high (>60 km/h) speeds. An optimal luminance level ensures that road users have suitable contrast perception and reduces the incidence of disturbing glare, together contributing to an overall improvement in driver visual acuity.

Luminance is the result of a combination of factors: the illumination of the road, the reflectance of the road surface and the geometric conditions of observation. Average road surface luminance [L], is described in the EN 13201-2 standard as the average of the measured luminance over the whole road surface. To calculate this value, there must be a defined calculation field (A). Generally, this should be an area containing two luminaires in a row, the first being 60 m in front of the observer. If there are more rows of luminaires or the space between luminaires varies, then measurements should be taken based on two luminaires within the same row that have the greatest distance between them. This, however, will not provide accurate results, especially if the general distance between luminaires varies a lot. In this case, it will be better to take the average of various measurements taken over a longer longitudinal distance from various points of observation. The variation of the measurements should be structured and factored into the overall calculation. Irrespective of how the final result is derived, the eye of the observer is assumed to be 1.5 m above the road surface.



A *The road surface luminance calculation field, with the point of observation **P** 1.5 m above the surface of the road and 60 m from the first luminaires to be included in the calculation.*

The calculation of the average road surface luminance is based on luminance values measured at evenly distributed points within the calculation field and is determined by the following formula or a mathematically equivalent one:

$$L = \frac{I \times r \times \Phi \times MF \times 10^{-4}}{H^2}$$

L *Maintained luminance. Measured in candela per square metre.*

I *Luminous intensity in the direction of observation (C, γ). Measured in candela per kilolumen.*

r *Reduced luminance coefficient for a light path incident with angular coordinates (ε, β). Measured in reciprocal steradians.*

Φ *Initial luminous flux of the light sources in each luminaire. Measured in kilolumen.*

MF *Product of the light source and luminaire maintenance factor.*

H *Mounting height of the luminaires above the road surface. Measured in metres.*

Sometimes it is necessary to check if an existing lighting system meets the average luminance requirements outlined in current standards. In such cases, when there are suitable weather conditions, it is possible to perform photometric measurements using a calibrated luminance metre. It is important that the weather be neither too hot nor cold as more extreme temperatures affect the sensitivity of the equipment. Wet road surfaces, dull light conditions and dirty roads can also negatively impact on the accuracy of measurement results.

A road's surface greatly affects the amount of light road users perceive, making assessment of its composition a crucial factor in determining required luminance values.

Reflectance

There is a close relationship between the construction material of a road surface and its luminance. Materials that have a high reflectance require a lower illuminance than materials with low reflectivity. If this basic principle is taken into account during the design of a road lighting system, it can result in a significant reduction in the amount of lighting needed and, therefore, the cost of the installation and its operation.

The reflective properties of a road surface depend on the structure of the construction material used, or more precisely, its macro- and micro-structure. If a road surface is dry, then both aspects of the structure affect reflectivity equally. However, if the road surface is damp, the microstructure becomes smoother and even mirror-like.

Rough macro-texture with rough micro-texture.

Rough macro-texture with smooth micro-texture.

Smooth macro-texture with rough micro-texture.

Smooth macro-texture with smooth micro-texture.

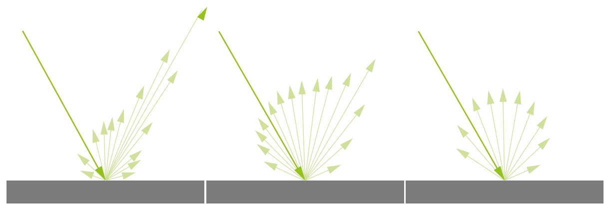
Road surface structures.

The classification of road surface structures depends on the country where the defined road is found although the most universally used system is the R system. The two most common road surfaces are R1, made from standard Portland cement concrete, and R3, made from asphalt.

Class	Road surface composition	Mode of reflectance
R1	Portland cement concrete Asphalt with aggregate including a minimum of 15 % artificial brightner aggregate	Mostly diffuse
R2	Asphalt with aggregate including a minimum of 60 % gravel sized larger than 10 mm Asphalt with aggregate including 10–15 % of artificial brightener aggregate	Mixed diffuse and specular
R3	Asphalt with dark aggregate – the surface becomes rough after several months of use	Slightly specular
R4	Very smooth asphalt	Mostly specular

R classification system.

Most road surfaces can be characterised using two values as adopted by the Commission internationale de l'éclairage (CIE). The first value refers to how dark the surface is, represented by the average luminance coefficient [Q_0]. This depends on the material content of the road surface. For example, a road surface with a high content of gravel will be lighter coloured than one containing dark coloured stones such as trap rock. Lighter surfaces reflect light better, meaning that they have a higher luminance level under the same light source. The lighter the surface, the higher the Q_0 value. The second value refers to the specularity of the surface, represented by the specular factor [S1]. This depends on how smooth the surface is. Smooth surfaces are shinier and reflect light very differently to rough surfaces. A smooth surface reflects light better, and so has a higher luminance value, but the light is reflected predominantly in one direction, decreasing the overall luminance uniformity ratio of the road. A rough surface reflects light less, meaning it has a lower luminance value but reflects the light more evenly, meaning that the luminance remains more uniform. The smoother the surface, the higher the S1 value. Both attributes have little effect on the longitudinal luminance uniformity ratio of a road surface, which is more dependent on the shape of the luminous curve.



Very smooth surface. Medium smooth surface. Very rough surface.

Reflective properties of various road surface structures.

System	Standard table / class	S1 limit	S1 of standard	Normalised Q_0 value
C	C1 C2	S1 < 0.4 S1 ≥ 0.4	0.24 0.97	0.10 0.07
R	R1 R2 R3 R4	S1 < 0.42 0.42 ≤ S1 < 0.85 0.85 ≤ S1 < 0.1.35 1.35 ≤ S1	0.25 0.58 1.11 1.55	0.10 0.07 0.07 0.08
N	N1 N2 N3 N4	S1 < 0.28 0.28 ≤ S1 < 0.60 0.60 ≤ S1 < 1.30 1.30 ≤ S1	0.18 0.41 0.58 0.58	0.10 0.07 0.07 0.08

Road surface classification.

A portland cement concrete road surface has a much higher luminance than a dark asphalt surface.

Good lighting uniformity is key to the visual comfort of road users and in turn to road safety.

ILLUMINANCE LEVEL

The illuminance method of lighting system design is used as an alternative to the luminance method as it is the only viable option in certain situations. Illuminance is the amount of light falling on a given surface. It is one of the easiest ways by which to quantify light because it is simple to measure using a luxmeter. This makes it an excellent base for road lighting design, or as a substitute in designs based on luminance where luminance measurements are difficult or impossible to perform. The unit most commonly used to describe illuminance level is lux [lx].

To determine a suitable illuminance level for a road surface, it is necessary to consider a variety of factors, such as traffic flow, crime risk and the amount of ambient luminance. These parameters are specific to each area of application and must be approached on an individual basis as well and being included in a general overview of the road.

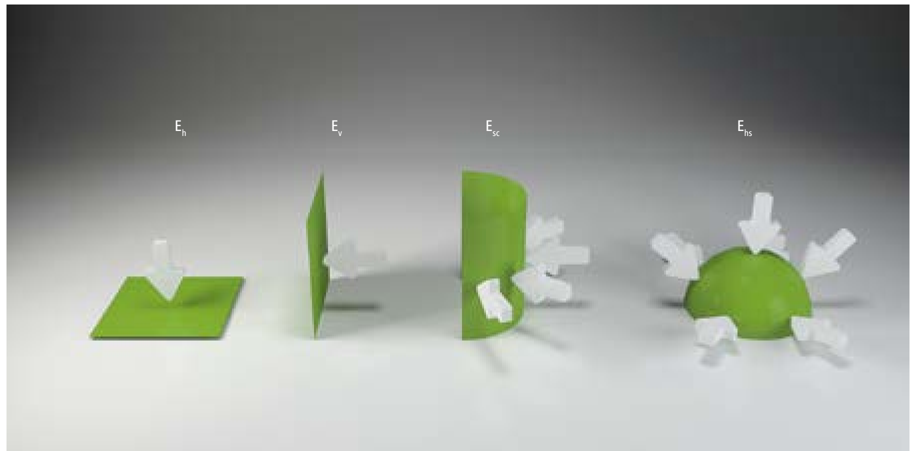
In the EN 13201 standard, there are four types of illuminance specified for different uses: horizontal [E_h], vertical [E_v], semi-cylindrical [E_{sc}] and hemispherical illuminance [E_{hs}], all of which are still quantified in lx (A).

In the context of road lighting design, horizontal illuminance is the amount of luminous flux falling on a road surface, meaning that the measurement plane need not always be horizontal. This type of luminance is used for both CE and S class roads. CE class roads are conflict areas such as shopping streets, complex road junctions, roundabouts and queuing areas. S class roads are those intended for pedestrians and cyclists, for example bike paths, pavements, emergency lanes and other areas that are separated from standard roads, in addition to residential roads, pedestrian zones, parking areas and schoolyards.

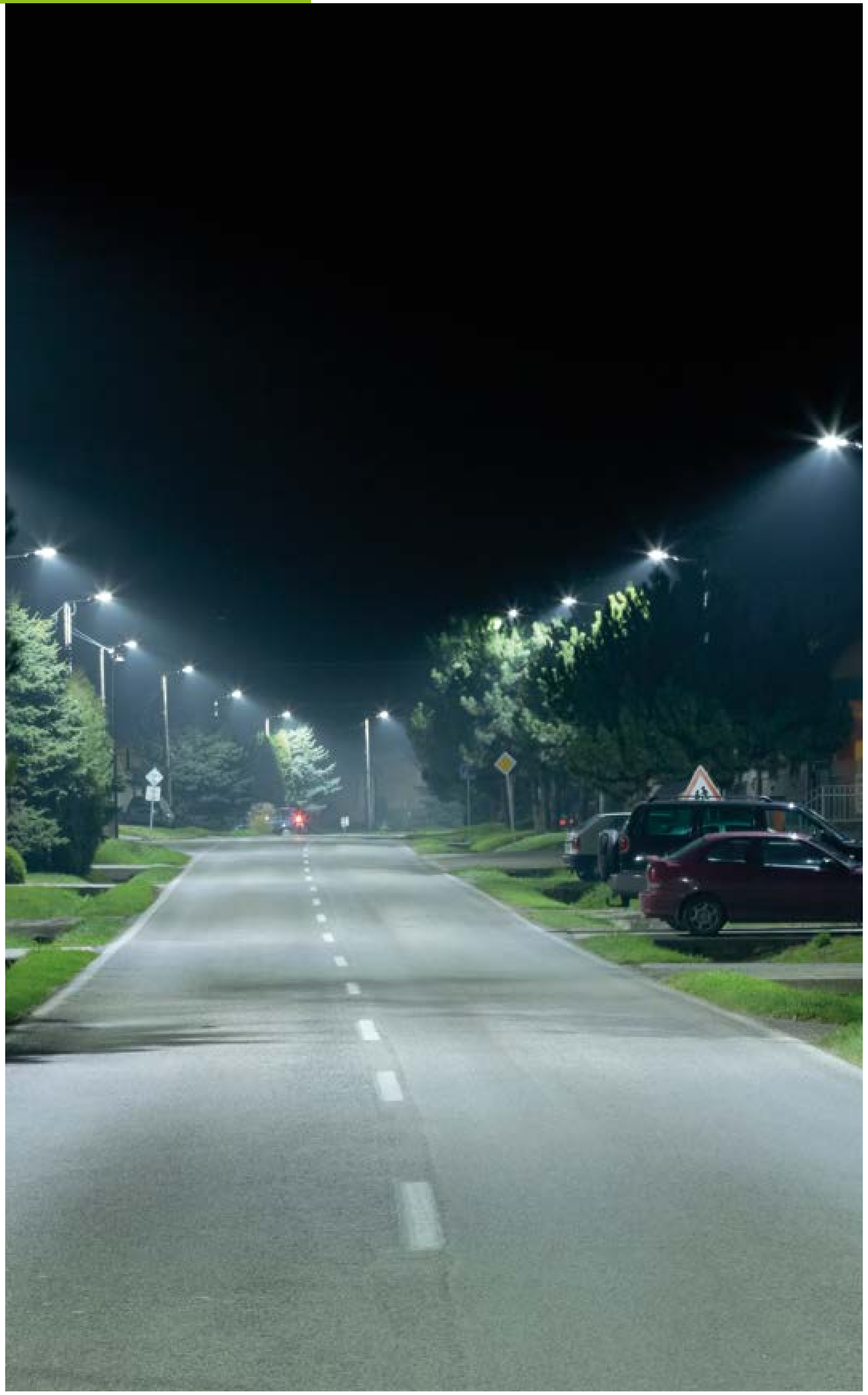
Vertical illuminance is the amount of luminous flux falling on a vertical surface. This type of luminance is the basis for EV lighting classes, which are used for areas that require vertical surfaces to be clearly visible, for example, the entrance areas of junctions or pedestrian and cycle crossings.

Semi-cylindrical illuminance is the amount of luminous flux falling on the curved surface of an upright semi-cylinder. This type of illuminance is used in ES class areas, which are predominantly pedestrian only areas. Semi-cylindrical illuminance helps people clearly see faces and obstacles from a distance, helping to reduce criminal activity and ensure people feel safe.

Hemispherical illuminance is the amount of luminous flux falling on the curved surface of a hemisphere placed on the assessed surface. This kind of illuminance is used in A class areas as an alternative to S classification of the same areas; lighting designers, in cooperation with customers, must choose which classification they prefer.



A *(Horizontal) illuminance, vertical illuminance, semi-cylindrical illuminance and hemispherical illuminance.*



LIGHTING UNIFORMITY

How uniformly light is distributed across a road's surface is a key factor affecting road safety. Evenly illuminated roads facilitate that drivers, cyclists and pedestrians clearly see into the distance, and aids early identification of obstacles and rapid reaction to dangerous conditions or events.

Uniform illumination is perceived as consistent and, therefore, visually comfortable as the human eye is not continually stressed and fatigued by the need to adapt to different luminance levels. To ensure adequate lighting uniformity for all road classes, it is necessary to install an appropriate number of luminaires with suitable Light Intensity Distribution Curves (LIDC), and to be able to respond quickly in the event of a luminaire malfunction.

The lowest permissible uniformity value is defined by the European EN 13201-2 standard. The specific value depends on the classification of road user, their typical speed, and traffic flow along with many other parameters. Based on all such parameters an appropriate longitudinal uniformity [U_l] and overall uniformity [U_0] values are determined.

Longitudinal uniformity is used in the luminance method of design, i.e., when designing the lighting for ME and MEW class roads. It is an important parameter for drivers who travel at moderate (30–60 km/h) and high (>60 km/h) speeds, where it is vital they be assured good visibility in the direction of movement. Longitudinal uniformity affects whether, and to what degree, the visible alteration between light and dark areas is perceived by road users. This is of particular importance during long journeys and at high speeds. The longitudinal uniformity of a road surface's luminance [U_l] is based on a calculation of the ratio between the highest and lowest road surface luminance in the centre of the driving lane, with the final U_l value being the lowest of the longitudinal uniformities of all lanes of the road.

Overall uniformity [U_0], which covers road surface luminance and horizontal and hemispherical illuminance, expresses the ratio of the lowest to the average value. It generally indicates a change in the luminance and/or illuminance of the road surface and is, therefore, important in assessing the suitability of the said road surface to be a background for traffic signs and other objects. This ensures visual comfort for road users.

Minimisation of glare improves the visual acuity and comfort of road users and acts to increase road safety.

GLARE & THRESHOLD INCREMENT

When drivers are exposed to excessive glare, their perception of and reaction to potential hazards is significantly slowed. For this reason, the minimisation of glare in road lighting is crucial to ensure safety.

Glare is an adverse visual sensation that causes discomfort and fatigue, as well as impairing or even obstructing vision. It is caused by strong or inappropriately distributed brightness within the field of vision or large spatial or temporal contrasts of brightness. Fundamentally, glare is the result of the retina of the human eye being exposed to considerably greater brightness than it has adapted to, considering the time it takes the eye to adapt to different luminance levels. Depending on the degree of glare, it can be classified as discomfort, disability or blinding glare. Discomfort glare is also referred to as psychological glare while on the contrary disability and blinding glare are physical phenomena.

Discomfort glare causes visual uneasiness without obviously impairing or restricting visual acuity. It is most often caused by sources of light within the field of vision that are dazzling and, to a degree, divert attention from the area of focus. As attention is dissipated, it causes general feelings of distress that are not necessarily directly attributable to sources of glare.

Disability glare is a higher level of glare caused by the presence of uncomfortably bright sources of light within the field of vision that make it difficult to recognise objects. This makes vision laborious and both visually and physically tiring, leading to feelings of insecurity and fatigue as well as negatively influencing performance.

Blinding glare is so intense that it reduces visual acuity to an absolute minimum, resulting in the inability to see. If such glare is experienced for an extended period, the effects can persist even once the cause has disappeared. In many cases, especially when driving or using roads, this kind of glare is very dangerous.

Threshold increment

In road lighting, threshold increment [T_I] is the quantification of loss of visual acuity due to disability glare caused by luminaires. It is applied to lighting installations used on ME and MEW class roads, and according to the EN 13201-2 standard, should have a value of no more than 10 % on motorways and major roads (ME1–2) and 15 % on minor roads (ME3–6).

The T_I value is calculated using the following or a mathematically equivalent equation:

$$T_I = \frac{65}{(\text{average road luminance})^{0.8}} \times L_v \,\%$$

$$L_v = 10\sum_{K=1}^{n} \frac{E_k}{\theta_k^2} = \frac{E_1}{\theta_1^2} + \frac{E_2}{\theta_2^2} + \dots + \frac{E_k}{\theta_k^2} + \frac{E_n}{\theta_n^2}$$

The constant 10 is valid for a 23-year-old observer. Constraints for other ages can be calculated using the formula, where A is the age of the observer in years. From this equation, it is clear that older people have a higher sensitivity to glare.

$$9.86\left[1+\left(\frac{A}{66.4}\right)^4\right]$$

The initial average road luminance (in cd/m²) is the average road luminance calculated for luminaires in a new state and for lamps emitting their initial flux. It is measured in lumens.

L_v Equivalent veiling illuminance. Measured in candela per square metre. Veiling illuminance is when there is a source of increased brightness between the eye of the observer and the object being observed. It results in the object being observed being less visible.

E_k Illuminance produced by the nth luminaire in a new state on a plane corresponding to the angle and height of the line of sight of the observer. Measured in lux.

θ_k Angle of arc between the line of sight of the observer and a line from the observer's eye to the centre of the nth luminaire. Measured in degrees.

Luminous intensity classes

In some cases, it is necessary to reduce disability glare in lighting installations where the threshold increment cannot be calculated. Luminous intensity G classes are also applied to such areas as a method by which to control the incidence of obtrusive light.

G1–3 correspond to areas with 'semi cut-off' and 'cut-off' style luminaires whereas G4–6 correspond to areas with 'full cut-off' luminaires that have flat covers that minimise light pollution.

This system of limiting glare can be used with the CE road classification system. Alternatively, when it is practicable to evaluate T_I values for all relevant combinations of directions and observer positions, the T_I value can be applied.

Class	Maximum luminous intensity in cd/klm			Other requirements
	at 70° [a]	at 80° [a]	at 90° [a]	
G1	–	200	50	None
G2	–	150	30	None
G3	–	100	20	None
G4	500	100	10	Luminous intensities above 95° [a] to be zero
G5	350	100	10	Luminous intensities above 95° [a] to be zero
G6	350	100	0	Luminous intensities above 90° [a] to be zero

[a] Any direction forming the specific angle from the downward vertical, with the luminaire installed for use

Luminous intensity classes.

Class	D0	D1	D2	D3	D4	D5	D6
Glare index maximum	–	7000	5500	4000	2000	1000	500

Glare index classes.

Glare index classes

Glare index classes D0–6 are assigned appropriate requirements for the restriction of discomfort glare. These classes are primarily intended for application to roads and areas illuminated for the benefit of pedestrians and cyclists. The glare index is I x $A^{-0.5}$, measured in candela per square metre.

I Maximum luminous intensity value in any direction forming an angle of 85° from the downward vertical. Measured in candela.

A Apparent area of the luminous parts of the luminaire in a plane perpendicular to the direction of I. If parts of the light source are visible directly or as images in the direction of I, class D0 applies. Measured in square metres.

Obtrusive light

Another consideration is the amount of light that is emitted in directions that are neither necessary nor desirable, commonly referred to as light pollution. This covers three key areas:

- In rural and suburban areas where light from road lighting installations can be seen at a distance across open country.
- In the case that light from a road lighting installation intrudes into properties.
- When light is emitted above the horizontal plane and scattered into the atmosphere, thereby obstructing a view of the night sky. Light emitted above the horizontal plane can be regulated by restriction of the upward light output ratio.

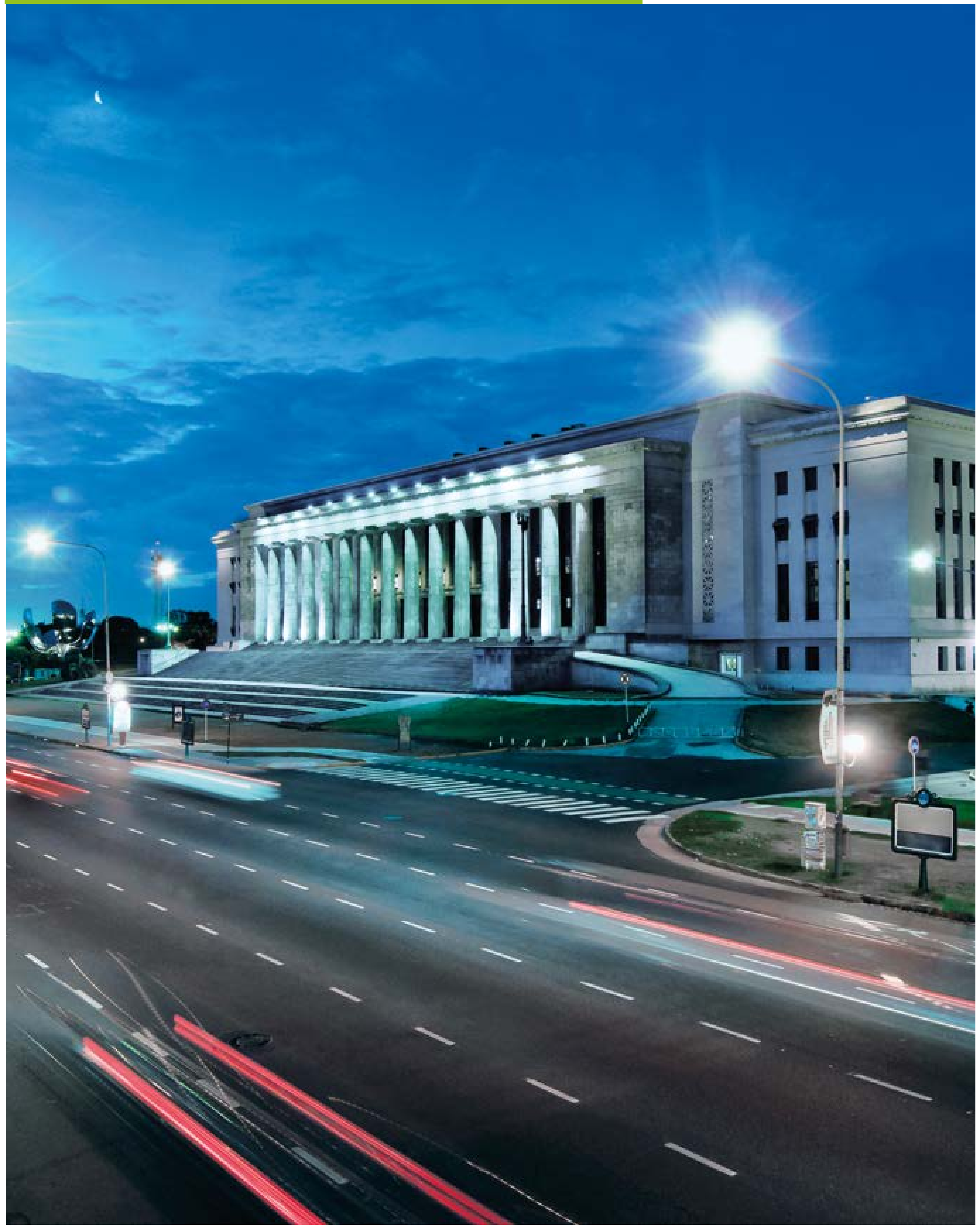
Road lighting must also address the area bordering the road as no illuminated space exists in isolation from its surroundings.

SURROUND RATIO OF ILLUMINATION

During the designing of a street lighting system, it is necessary to ensure optimal illumination also of the area immediately adjacent to the road. Too little or too much brightness in this area is demanding on the adaptability of road users' eyes, reduces the visibility of pedestrians, cyclists and potential obstacles and, therefore, the driver's ability to identify dangerous situations in time to avoid them.

The European EN 13201 standard defines the surround ratio of illumination for a road [SR] as the average illuminance of areas just along the outside edges of the road in proportion to the average illuminance of areas just along the inside edges of the same road.

For ME and MEW class roads, the EN 13201-2 standard defines a minimum SR value of 0.5, meaning that the areas just along the outside edges of the road must have an illuminance of at least 50 % of that of the road. However, our experience has shown that this value is insufficient and that an increased SR value improves visibility and the ability of drivers to perceive contrast. Nevertheless, this rule only applies to a certain degree. According to studies based on the impact of different SR values on the ability of the human eye to perceive contrast, drivers perform better when there is an SR value of around 1, with performance again reducing at an SR value of more than 1. This suggests that the normative SR value of 0.5 is not optimal, and we recommend that it be increased, maximally to a value of 1.

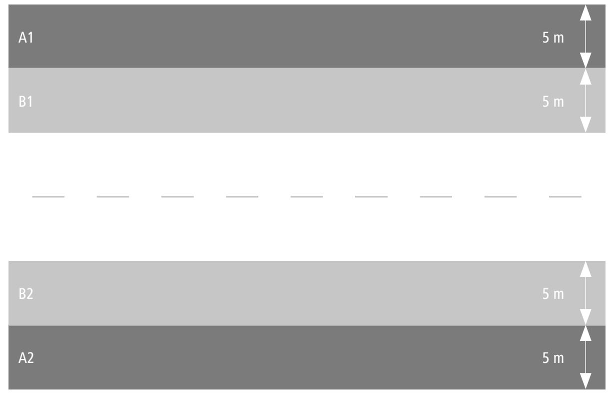


There are three ways to determine the calculation areas of the SR value. All four calculation areas, those both inside and outside the edge of either side of the road, must be of the same width. The first method (A) determines that the calculation areas are 5 m in width. The second method (B) determines that the calculation areas be equivalent to half the total width of the road. The third method (C) is applied when there is an obstacle to an outside calculation area that means it cannot be 5 m wide or equivalent to half the width of the road. In this case, the narrowest point of the outside calculation areas becomes the determined width. The method resulting in the narrowest determined width should be used. If a road has two or more lanes on both sides, it is treated as a single road unless the central reservation is more than 10 m wide, in which case each side is treated as a single road.

The surround ratio of illumination is calculated using the following or a mathematically equivalent equation:

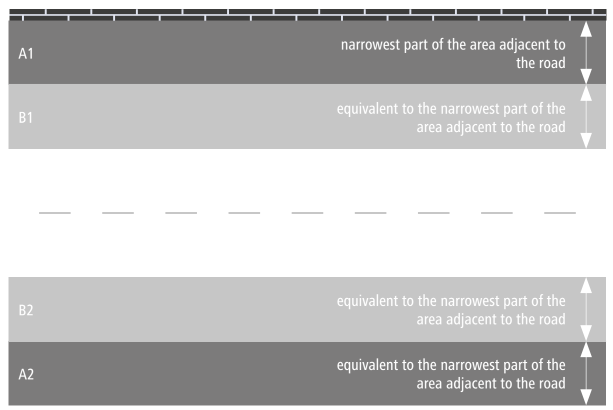
$$SR = \frac{\text{Average illuminance of A1 + A2}}{\text{Average illuminance of B1 + B2}}$$

A1 and A2 – calculation area adjacent to the road
B1 and B2 – calculation area within the road



A *All calculation areas = 5 m wide.*

B *All calculation areas = equivalent to half the width of the road.*



C *All calculation areas = equivalent to the width of the narrowest point of A1/A2 due to the presence of an obstacle (such as a wall).*

Light sources with a higher Colour Rendering Index enable better colour and object recognition, contributing to increased safety and feelings of security.

CORRELATED COLOUR TEMPERATURE

The Correlated Colour Temperature (CCT) of white light emitted by a light source refers to its colour properties, and differs between light source types based on the used technology and design, and the age of the light source. The latest research into the effects of CCT on road safety has shown that the use of lighting with a suitable CCT can help reduce the incidence of accidents and criminal activity.

The white light emitted by light sources can be divided into three basic groups: warm white with a CCT of less than 3300 K and perceived as orange to yellow, neutral white with a CCT of 3300–5000 K and perceived as slightly yellow or natural, and cool white with a CCT of 5000–8000 K and perceived as natural to slightly blue. There are also light sources that emit what is commonly known as 'skywhite', which exceeds standard CCT values, reaching as high as 12,000 K.

European standards do not currently stipulate CCT values for street and urban lighting, and many lighting installations use high- or low-pressure sodium lamps that emit very warm white almost monochromatic light that is perceived by the human eye as yellow or orange. Based on the findings of research, and on our own experience, we believe the best solution for street and urban lighting installations is to use light sources that emit white light since its spectral composition is closest to that of daylight and the most natural for human vision. This is based on the fact that white light has a higher S/P ratio – the ratio between scotopic and photopic vision – meaning that it is literally more effective at a given illumination level in terms of supporting visual acuity and perception of contrast. This leads to improved road safety, easier recognition of faces and objects and better recording of events by CCTV cameras in the fight against crime.

Light source	LED	Metal-halide	High-pressure sodium	Low-pressure sodium
CCT [K]	2700–8000	4200–6000	2000–2200	1800

CCT comparison by light source.

CCT comparison.

Colour perception of high-pressure sodium compared to LED with CRI ≥ 70.

COLOUR RENDERING INDEX

Colour rendition has long been considered of lesser importance in street and urban lighting design. However, as research has proven the positive impact of proper colour rendition on traffic and pedestrian safety after dark, it is increasingly included as a fundamental in modern lighting trends, placing due emphasis on the selection of light sources with good colour rendering properties.

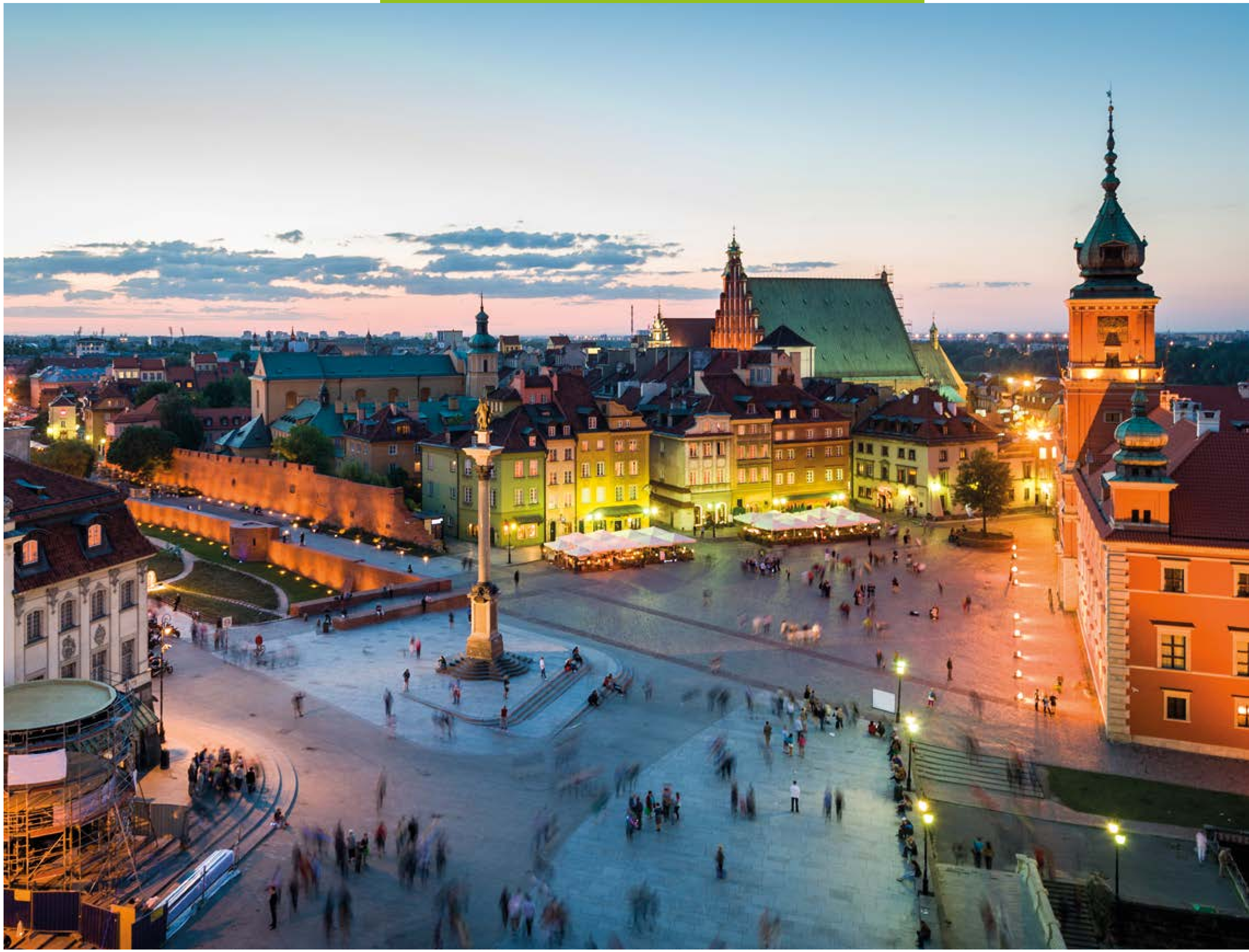
The influence of an artificial light source on the appearance of colours is expressed by the Colour Rendering Index (CRI), which indicates how realistically each light source can render colour. In order to define the CRI of a light source, it must be compared to that of a neutral control light source, most commonly daylight. Both the control and test light source must have the same CCT properties for the comparison to be accurate as CCT is one of the key determiners of CRI. The more accurate the colour rendition of a light source, the higher its CRI value, with daylight having CRI = 100. To assess colour rendition, fifteen test colours are compared, each receiving an individual rating with the average of the first eight referred to as the Ra value, the standard expression of CRI used throughout the industry.

From a practical point of view, the CRI value of a light source is one of the most important parameters to consider during light source selection. This is especially the case in areas with pedestrian and cyclist traffic, at particularly unclear points on a road, and where easy recognition of faces and objects is important. Currently, most lighting installations still rely on the use of low-pressure sodium lamps with their almost monochromatic light. To achieve suitable colour rendition, we recommend the use of LED or metal-halide light sources with CRI values of 70 Ra or higher.

EMOTION

Creating a pleasant atmosphere and a sense of safety are fundamental factors that influence our perception of and comfort in every outdoor space.

An easy element to overlook, the emotional impact of street and urban lighting can have a profound influence on our perception of public spaces, sense of security and in turn the vibrancy and image of a town or city.



The division between day and night is becoming increasingly blurred as our societies function on a 24-hour basis. This makes it more important than ever to create a pleasant and appealing atmosphere in our towns and cities throughout the night, as a positive visual experience is paramount in a person's perception of a space and their resultant psychological comfort. Although this is primarily achieved through the use of architectural lighting to create interest and atmosphere, the role of standard street and urban lighting should not be underestimated.

Even the safest streets, squares and parks can appear daunting at night if badly illuminated. The unnatural yellow of high-pressure sodium lighting and the incidence of dark areas and shadows make a space feel unsafe. This is in part because we experience greatly reduced visual acuity under these conditions and cannot effectively recognise people, obstacles and danger from a distance. To resolve these issues, it is of vital importance that a lighting system be designed to properly illuminate an entire space, minimising areas of shadow and doubt. This requires the professional and careful analysis of what lighting is needed and where, and the appropriate setting of each luminaire so that it distributes its luminous flux effectively. It is also highly beneficial to use LED light sources that emit white light, which has similar properties to daylight and is perceived as brighter and more natural in addition to improving visual acuity.

The use of cooler coloured white light also makes a space feel cleaner and airier, creating a fresh and activating atmosphere. On the other hand, warmer light colours give a more cosy feeling. It is important to bear in mind what atmosphere would be most beneficial in each case, considering structural, historic and cultural features. In some cases in may even be useful to combine cooler and warmer light to highlight complex areas to their best, with the added advantage of its aiding spatial differentiation.

More information about the effects of street and urban lighting on safety and security can be found in the **Light & Safety** section at the beginning of this book.

ECOLOGY

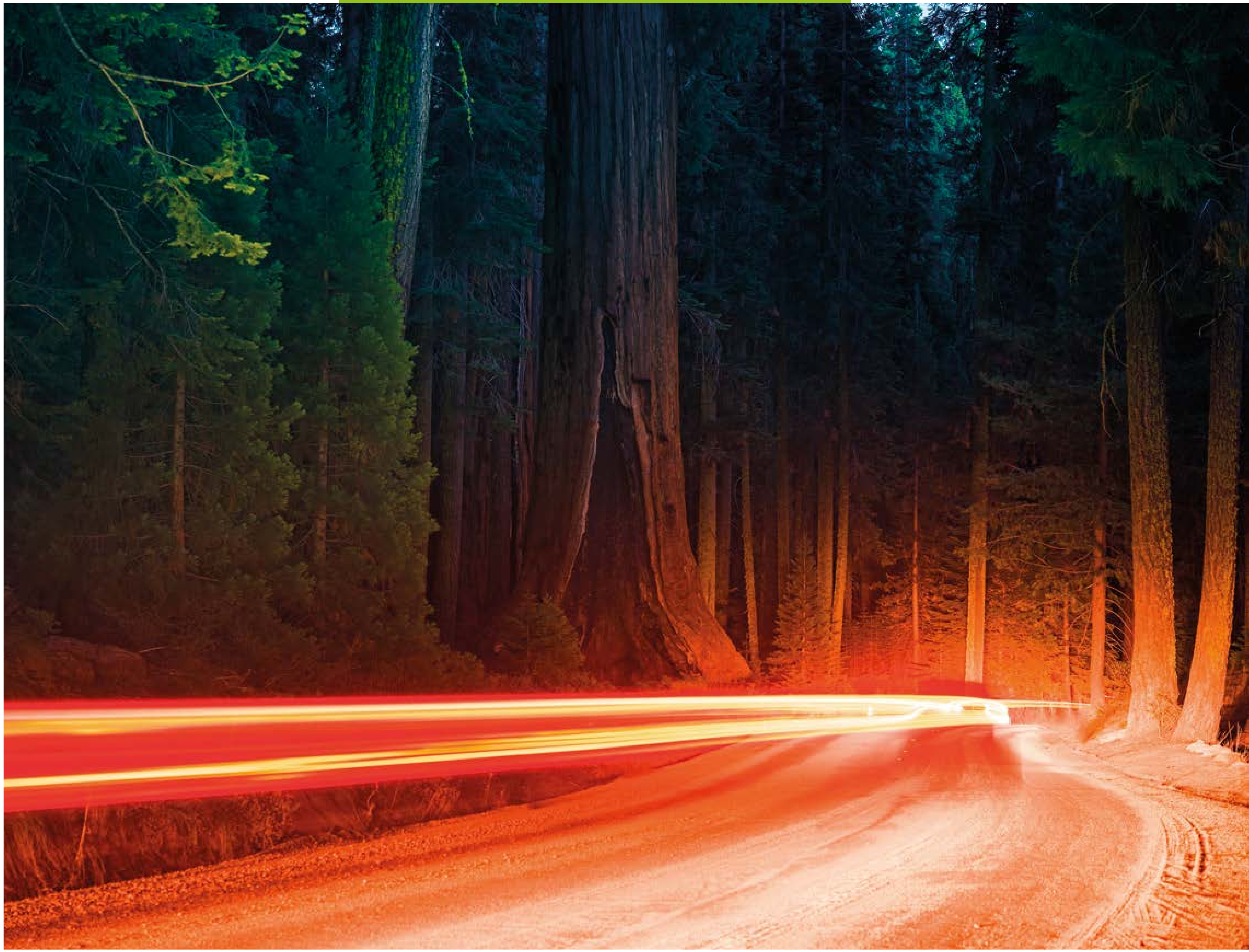
Lighting has a huge impact on the world around us, and thanks to technological advancement, also great potential in helping secure our planet's future.

ECO FRIENDLY

Respect for the fragile equilibrium of the environment has been core to innovation and growth in many industries over the past few decades. The lighting industry is no exception, having great ecological potential and consistently pushing to the forefront environmental responsibility and understanding.

Gone are the days when the provision of light is enough. Now light source and lighting technologies are required to be energy efficient, recyclable and have long lifetimes as well as to be effective and have a low environmental impact during production, use and disposal.

All of these factors combined make for an ecologically sound solution and a cost effective one, both advantages being strong driving forces behind technological development and customer uptake.



More than 90 % of all light source development is occurring within the field of LED.

THE LATEST LIGHT SOURCE TECHNOLOGY

The time when people applauded Swan and Edison are long gone. Although history will forever remember them as the fathers of artificial light, science is rapidly and consistently driving advancement in this area.

Energy resources are limited and prices are constantly rising. Awareness of this makes it more and more important to achieve greater light source efficiency and lower energy consumption. A few years ago, high-pressure sodium lamps were the light source of choice but are now rapidly losing ground to LED technology. Compared to conventional light source technologies, LED has many advantages including more effectively transforming consumed electrical energy into visible light, consuming less energy, emitting negligible amounts of UV and IR radiation, and containing very low levels of hazardous materials. In terms of light source development, more than 90 % of innovation is taking place in the field of LED. However, we must remember that the driving force behind both LED and conventional light source development is their efficiency, with conventional lamps being replaced by long-life versions, and even standard metal-halide lamps by second-generation ceramic filament ones.

The key indicator of the efficiency of a light source is its efficacy, how much light is emitted in lumens in relation to the power consumed in watts, resulting in an easily quantifiable lumens per watt value [lm/W]. This is a core parameter for any lighting designer when designing a lighting system. In this respect, LED proves itself by offering efficacies far higher than those of conventional light sources. The value can be calculated using the following equation:

$$\text{Light source efficacy} = \frac{\text{Lumen output of light source [lm]}}{\text{Installed power of light source [W]}}$$

Currently, despite being far more efficient and providing very high quality light, LED technology has not yet replaced conventional technology, mainly due to the higher initial price. However, to gain a clear view of the situation we must look at the wider context as lower power consumption, reduced maintenance costs and long lifetimes mean that LED provides an excellent return of investment.

Light source	Efficacy [lm/W]	Lifetime [hours]
Mercury vapour	40–60	12,000–24,000
Metal-halide	70–110	6000–20,000
High-pressure sodium	60–150	12,000–32,000
Low-pressure sodium	80–200	12,000–18,000
Fluorescent*	60–100	10,000–20,000
Induction*	70–90	60,000–100,000

* There is a big decrease in the efficacy of the light source at lower temperatures

Light source comparison.

The materials used in the construction of the luminaire and its optical system have the greatest effect on system efficacy.

SYSTEM EFFICACY

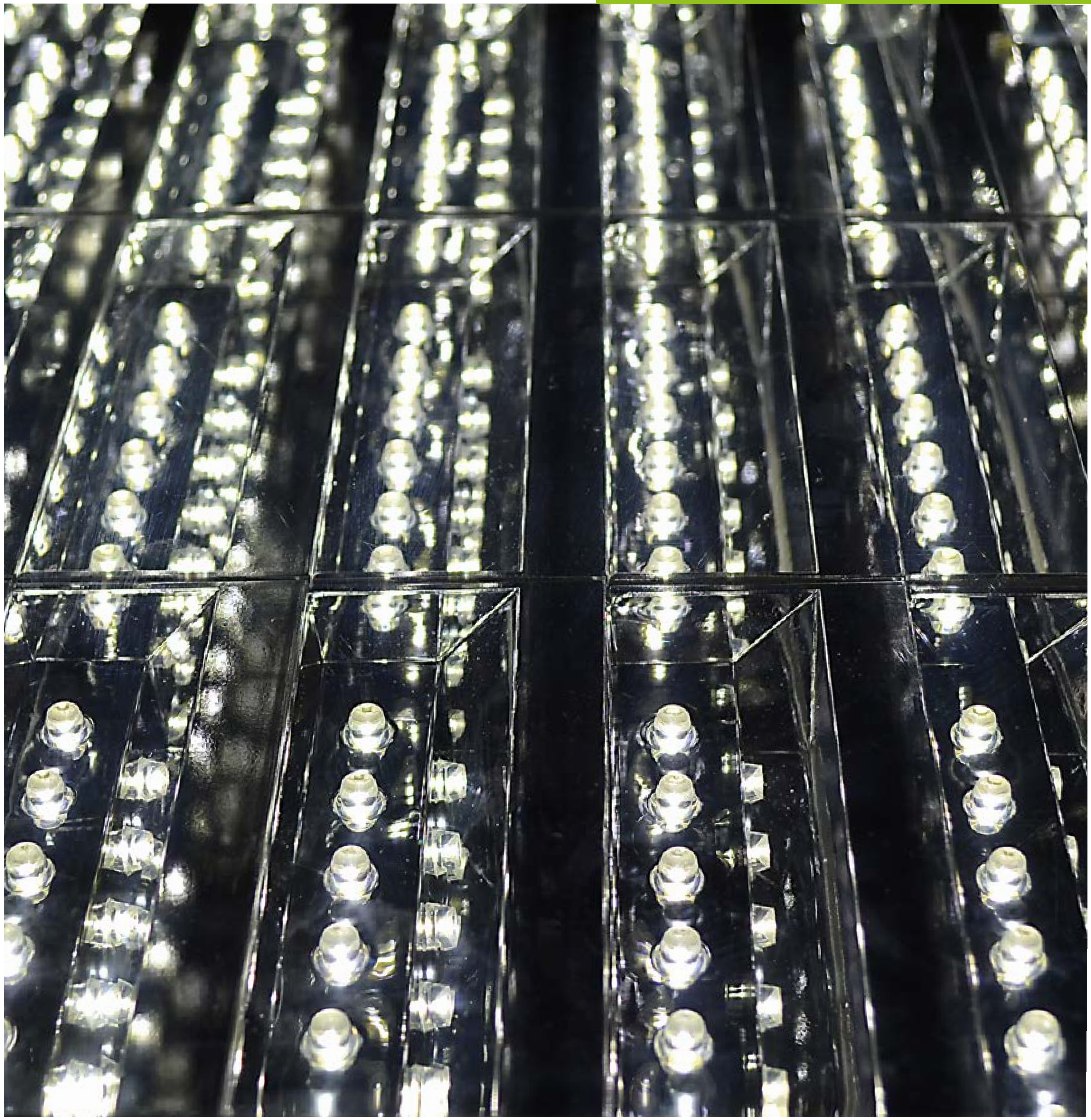
Light source efficacy is only one part of the equation, as the use of inappropriate and ineffective luminaires negates the positive effects of the light source. Therefore, it is vital that suitable luminaires are also part of the plan.

System efficacy refers to the effectiveness of the luminaire itself, how well it can direct the light while reducing losses on the surfaces of the optical system to a minimum. This is measured in much the same way as light source efficacy, with the light output of the luminaire in lumens divided by its overall power consumption resulting in a lm/W value.

$$\text{System efficacy} = \frac{\text{Lumen output of luminaire}}{\text{Installed power of luminaire}} \left[\frac{\text{lm}}{\text{W}}\right]$$

Another important value is the Light Output Ratio (LOR), which expresses the ratio of the light source output to the luminaire output, thereby quantifying the amount of energy lost within the optical parts of a luminaire. LORs are calculated using the following equation:

$$\text{LOR} = \frac{\text{Lumen output of luminaire}}{\text{Lumen output of light source(s)}} \%$$



How to make an effective luminaire

The materials used in the construction of a luminaire have the greatest influence on its effectiveness. Optical materials are used to diffuse the light, modify its distribution and change its spectral composition. They are divided into two types, those that reflect, and those that transmit. Aluminium, with various surfaces finishes, is the most common material used for reflectors, while glass and plastics are used for transmitting parts such as lenses and diffusers. Every material has different reflectance and absorption properties, but generally the more effective the materials used, the lower the amount of light lost on or within the optical parts, and the higher the LOR and system efficacy of the luminaire.

However, effectiveness is not only dependent on the materials used, but also on the shape and design of the optical system. Well-designed optics ensure that the greatest amount of light is directed as desired with minimal losses. Modern computer applications calculate the optimal mathematical and geometric properties for the individual parts of a given optical system.

In modern street and urban lighting luminaires, the predominant optical technologies are lenses or some kind of lens and reflector hybrid. Such optical systems afford the highest level of flexibility in terms of the ability to modify light distributions to perfectly suit a specific application, in combination with having high LOR values.

It is important to keep in mind protection of ourselves and the environment when choosing appropriate technology.

LIGHT SOURCE THERMAL OUTPUT

The part of the light spectrum visible to the human eye ranges between infrared (IR) and ultraviolet (UV). Even though we cannot see IR radiation we can still sense it, as heat.

All light sources emit a certain amount of IR radiation, energy that is lost as heat rather than being useful as light, therefore, the lower the amount of IR radiation a light source emits the more effective it is. From this point of view, the incandescent bulb is the least effective as 95 % of the energy consumed is emitted as thermal radiation and only 5 % as light. At the other end of the scale, commercially available LED light sources emit around 55 % of their consumed energy as light, making them 1000 % more effective.

DANGEROUS MATERIAL CONTENT

When we think of the dangers associated with broken light sources, it is usually of being cut. In fact, the risks connected with most types of light source are far greater and seriously impact our health and the environment.

The main reason we say this is because most light sources contain mercury, a highly toxic heavy metal and vital component especially of fluorescent and metal-halide lamps. Despite a great deal of research being done to find a substitute for mercury in light sources, none has yet been found. Alternative light sources that are not dangerous to people and the environment are so costly that they are not financially viable for mass use.

The risk associated with light sources is not present during general use. It is only if the lamp is broken during handling that they pose a threat by releasing vapours into the air, or if disposed of inappropriately that dangerous substances can contaminate the soil and possibly water. This is of particular importance as heavy metals do not decompose and so become a permanent element of the environment.

Another factor, although more of an operational one, is that light sources containing hazardous materials are difficult and expensive to dispose of as they must be dealt with in accordance with stringent legislation.

SERVICE LIFETIME & MAINTENANCE COSTS

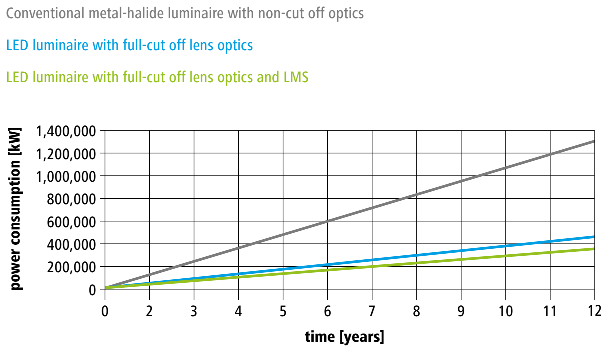
When designing a streetlighting system, one of the key factors to consider is the service lifetime of the chosen light sources and the cost of their maintenance and replacement.

The most commonly used conventional light sources for streetlighting applications are high-pressure sodium and metal-halide. These light sources have relatively long lifetimes that, based on 11 hours of operation every day, mean they can last for approximately five years. At this point, the administrator of the lighting system must pay for their replacement. However, such light sources also need checking and maintaining in order that faults are detected and resolved in due course. Both replacement and maintenance require the use of specialist equipment, such as an elevated work platform, and potentially necessitate the closing of a road or at least restriction to traffic flow.

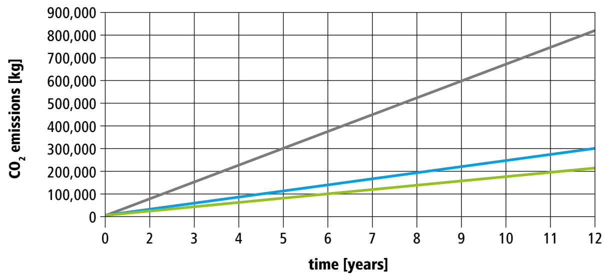
LED light sources offer many advantages in the area of service lifetime and maintenance costs. At first sight, LED light sources appear to be a more costly solution based on initial investment as they are more expensive than conventional light sources. However, their use provides many advantages that balance this issue. The first and biggest advantage is that they have very long lifetimes, commonly of 100,000 hours for streetlighting application. This means that an LED light source in operation 11 hours per day, 365 days per year can last for almost 25 years, around five times longer than both metal-halide and high-pressure sodium light sources. Another significant advantage is that LEDs reach the end of their life when their light output falls below 70 %, or in some cases 80 %, meaning that they do not just stop working, or worse still, explode as some metal-halide lamps have been known to do. Rather, they simply emit less light. This allows for careful and timely preparation for their convenient replacement.

In terms of maintenance, LEDs have exceptionally low failure rates, with approximately two in every million failing. This removes the need for their maintenance, thereby reducing the burden of the lighting system on the administrator as well as associated costs.

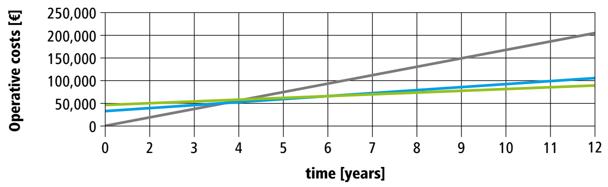
Lastly, manual control of a lighting system can also be called a type of maintenance. By using some type of LMS, it is possible to also remove this obligation.



Power consumption.



CO_2 emissions.



Operative costs.

Miantaining and changing light sources in streetlighting applications is a complex, costly and often inconvenient task.

The service lifetime of a light source influences how often if needs replacing as well as the costs and obligations involved in their maintenance.

Parameters	**Conventional metal-halide luminaire with non-cut off optics**	**LED luminaire with full-cut off lens optics**	**LED luminaire with full-cut off lens optics and LMS**
Street category	ME3	ME3	ME3
Light source			
Type	Metal-halide (MT)	LED	LED
Power consumption [W]	250	97	97
Lifetime [hours]	16,000	100,000	100,000
Luminous flux [lm]	20,000	10,850	10,850
Number of light sources / units	1	1	1
Luminaire			
Control gear	CCG	ECG	ECG
Power consumption (including CG) [W]	270	97	97
LOR [%]	75	100	100
Net luminous flux [lm]	15,000	10,850	10,850
Number of luminaires	100	100	100
Purchase price			
Light source [€]	25	0	0
Luminaire [€]	0	344.75	371.25
Complete initial installation [€]	2500	34,475	37,125
Operative parameters			
Average time of operation per year [hours]	4004	4004	4004
Total power consumption of installation [W]	27,000	9,700	9,700
Lighting control	none	none	Step-dimming LMS with astro clock
Average time of operation at 100 % luminous flux [hours]	11	11	5
Average time of operation at 50 % luminous flux [hours]	0	0	6
Operative costs			
Electricity rate [€]	0.15	0.15	0.15
Daily electrical energy consumption per luminaire [W]	297	106.70	77.89
Daily cost of consumed electrical energy per luminaire [€]	44.55	16.01	11.68
Monlthy electrical energy consumption per luminaire [W]	9033.75	3245.46	2369.18
Monthly cost of consumed electrical energy per luminaire [€]	1355.75	486.82	355.38
Yearly electrical energy consumption per luminaire [W]	108,405	38,945.50	28,430.22
Yearly cost of consumed electrical energy per luminaire [€]	16,260.75	5841.83	4264.53
CO_2 emissions			
Per year [kg]	69,379.20	24,925.12	18,195.34
Maintenance			
Number of maintenance cycles per 12 years	3	0	0
Time taken to change a light source [hours]	0.25	n/a	n/a
Purchase price of service hour [€]	20	n/a	n/a
Maintenance fee [€]	3000	n/a	n/a
Savings & payback times			
Difference between overall costs [€]	–	31,975	34,625
Power consumption-related savings per year [€]	–	-10,418.93	-11,996.22
CO_2 emissions reduction per year [kg]	–	-44,454.08	-51,183.86
Payback time [years]	–	3.1	2.9

Total costs of ownership (TCO) comparison.

It is important not to underestimate the negative effects of light pollution.

LIGHT POLLUTION

Light pollution is light that is directed neither where needed nor desired. It can be broadly categorised into several types: glare, light trespass, over-illumination, clutter and skyglow. Glare is covered in an earlier chapter.

Light trespass is light that falls where it is not supposed to. Streetlighting is intended to illuminate roads, public areas and pavements, not fall onto or into nearby buildings. By minimising light trespass, it is possible to avoid discomfort or nuisance caused by misdirected illumination.

Over-illumination is the provision of too much light. This could be due to the use of luminaires that emit more light than needed, by light being directed in a way that it falls where it is not required, and even by the substitution of older light sources with newer and more effective ones with the same power.

Light clutter is the excessive concentration of light sources in an area, resulting in the area having a much higher luminance than surrounding ones. This can cause discomfort and be visually distracting in a similar way as low-level glare.

Skyglow is the light seen above a populated area. It is caused by light that is emitted into the sky in an upward direction being scattered back down by the atmosphere. This effect is further exacerbated by cloud cover and air pollution.

There are many documented effects of light pollution. In populated areas, it is now very difficult or even impossible to see a dark sky and view the stars. However, this effect has become so pervasive in modern life that we tend to accept it as normal. Moreover, some cities are proud of their excessive illumination and refuse to recognise it as light pollution.

Other well-observed effects include those on insects, bats, birds and animals like turtles and frogs. Such creatures are attracted to artificially bright light, especially that with a high UV content. What's more, light pollution has a proven impact on the physiology of species with set diurnal and nocturnal habits. The effects of artificial light on ecosystems are referred to as ecological light pollution, which can disturb feeding, breeding, navigation, hunting and in birds, migratory behaviour, bringing various negative consequences. It is a common experience to see insects swarming around street luminaires, which is both harmful to the insects and unpleasant for humans who must contend with the annoyance. However, these effects do not exist in isolation. New research carried out in the UK also found that light pollution affects entire insect and invertebrate communities by increasing the number of predatory and scavenger species both at night and during the day. This would suggest that any changes are permanent and could affect the survival of other species, causing widespread changes in the species composition of ecosystems. It is to be noted that plant life is also affected both directly and indirectly as a result of changing animal behaviour.

Insects are attracted to bright light, especially light with a high UV content.

Cities are often proud of their lighting, which threatens dark sky preservation.

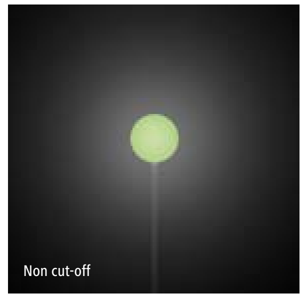
A reducunction in light pollution requires the use of appropriate measures, varying from the use of different light sources and luminaire optics to the implementation of LMS. However, paramount in the fight against light pollution is correct lighting design, making sure that people only see the area being illuminated and not the light source itself, in accordance with the requirements laid down in the EN 12464-2 and, if possible, surpassing them by putting into practice findings from the latest research.

Light sources

Metal-halide light sources emit much UV radiation, making them particularly detrimental to nocturnal animals and insects. For this reason, insects often collect within luminaires, reducing their effectiveness. LED light sources emit little UV radiation, and so are a better option in this respect. One disadvantage of LED is that they emit light strong in the blue part of the spectrum, which disproportionally pollutes the night sky. However, this can be more than compensated for by use of sophisticated optical systems that vastly reduce the amount of light ineffectively directed.

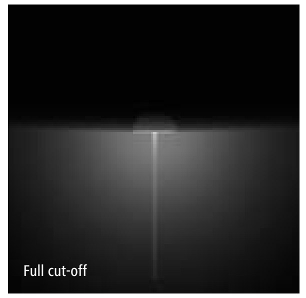
Optical systems

The optical system of a luminaire is responsible for how its light is distributed and directed (A, B, C). Commonly used optical elements include reflectors, although modern LED luminaires often include lenses that allow for more precise and effective control of the light and as a result minimise light pollution and the energy losses associated with wasted light.



A Generally pole mounted luminaires with a globe shaped top that emits light is all directions. They create a lot of light pollution and are very glaring. They are rarely used on roads but are still often found in residential and urban areas.

B Still the most common type found and usually pole mounted cobra head luminaires that do not emit light upwards. As the optics drop below the luminaire housing, light is distributed well over larger areas making them ideal for high mounting, but as much as 5 % of the light it emitted above 90º.



C Already popular, the optics do not extend below the housing of the luminaire so that no light is emitted above 90º. The light distribution is more defined, meaning that the light falls only where needed, reducing light pollution and energy consumption.

EFFICIENCY

As conventional energy resources decline and energy prices rise, it becomes more and more important to reduce our energy requirements.

With consistently increasing demand for energy and the associated environmental impact, we want to make choices that are not only financially, but also ecologically sound. This is especially the case for such an investment as the replacement of a street or urban lighting system as such systems consume huge amounts of electrical energy. Unfortunately, however, much of the energy consumed it emitted as light that never benefits anyone. To this end, one of the most effective ways to save energy and thereby reduce operational costs is to use some kind of control system, commonly called a Lighting Management System (LMS).

An LMS reduces energy consumption by ensuring that the lighting system only provides the light needed, where and when needed. As with any type of lighting system, it is simply not necessary for all luminaires to emit 100 % of their light output all the time. Consequently, a public lighting LMS acts to reduce light output based on time, traffic flow and pedestrian frequency while still assuring the provision of sufficient illumination to meet needs at each given time. It also means that regulation is fully, or at least partially, autonomous, removing the factor of human error and bringing increased comfort and reliability.

There is a wide array of control methods and protocols, meaning that there is certainly a suitable solution for every application. Such regulation can also bring additional benefits, including remote monitoring of the lighting system in terms of power consumption, and importantly, also failures or other problems in real-time. The latter function is of special note as, in a traditional lighting system, light source or luminaire failures and issues often go unnoticed for prolonged periods, are time-consuming to find and resolve, and as a result costly. Furthermore, such issues can result in insufficient illumination of risk areas and can thus be highly detrimental to road and pedestrian safety, a factor that alone more than justifies the use of an LMS.

There are several methods by which to regulate lighting levels, from simple switching to complex dimming that can adapt to real-time needs. In all cases, it is necessary to have a manual override function for the case that problems occur such as device failures.

The simplest way to save energy is to ensure lighting is only turned on when needed.

SWITCHING

This is a fundamental function of every lighting system, the simple turning on and off of the lighting at appropriate times. However, the use of automated switching reduces the factor of human error and can, depending on the method used, adapt to need.

Lighting management in the form of switching on at sunset and switching off at sunrise, or switching off the lighting during quieter hours, is now considered an outdated and insufficient solution and is best combined with some form of control, such as dimming.

Single phase switching

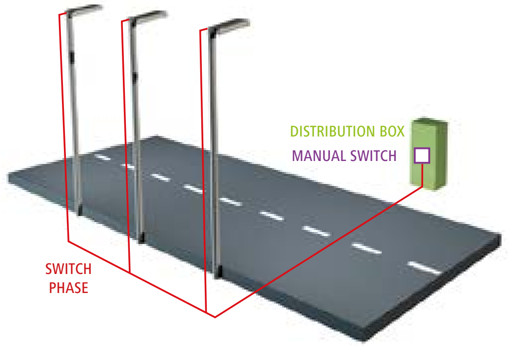
The most basic form of control consists of using a single phase to power the lighting system, the power to which is switched on or off directly in the distribution box (A). This is usually done remotely from a central control location but employs no extra method of control.

Single phase switching astronomical clock

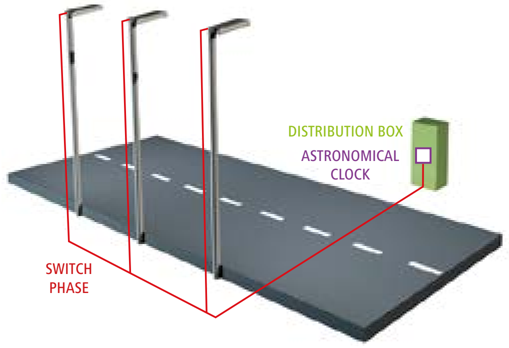
This kind of astronomical clock function is programmed into a driver located in the distribution box (B). It works by calculating exact sunset and sunrise times for each day, based upon which connected luminaires are switched on or off using single phase switching.

Twilight sensors

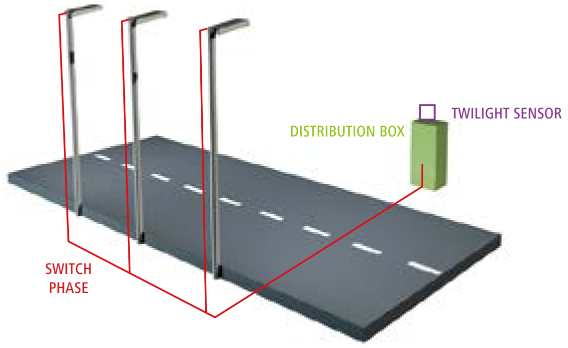
One of the simplest ways to control luminaires according to need is to use photocells, also known in this application as twilight sensors (C). In this method, power to the luminaires is switched on and off according to input from a twilight sensor located on or near the distribution box. Connected luminaires are switched on when the ambient light level falls below a certain value at dusk, and switched off once the ambient light level exceeds a certain value at dawn. It is possible to use this kind of switching in combination with single phase switching astronomical clock functionality.



A *Single phase switching.*



B *Single phase switching with astronomical clock.*



C *Single phase switching with twilight sensor.*

Dimming offers the greatest energy saving potential by allowing safe reductions in light levels.

DIMMING

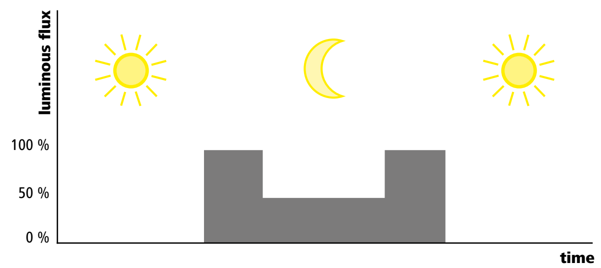
Dimming is when the level of illumination emitted from a light source is reduced according to need or desire. This brings both energy and operational savings.

For streetlighting, dimming is appropriate to use when roads and public areas are quieter, which in turn changes the road classification to one less demanding of the lighting system. For example, in a residential area, there are few vehicles or pedestrians out in the early hours of the morning, so it is possible to reduce the lighting level by maybe 40 % while still meeting the requirements of the road classification relevant at that particular time.

There are three methods of dimming. Simple step dimming, often called bi-level dimming, is when the lighting can be set at two defined levels at set times. Multi-step dimming is when the lighting can be set to several different levels at various times. Both of these types of dimming are implemented in sudden steps with an immediate change from one light level to another. Then there is linear dimming, which is implemented gradually so that light level changes are not sudden, but rather take several seconds. This is more visually comfortable as the change is not a shock to the eye.

Step dimming (bi-level)

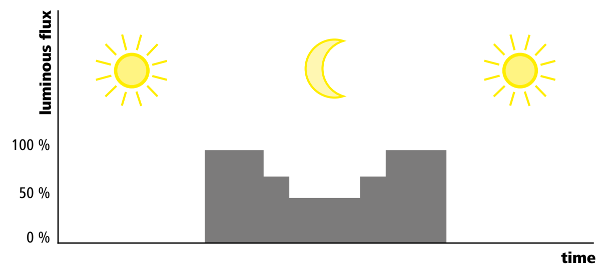
This basic dimming regulation is implemented using either analogue or digital control (A). An advantage of step dimming is that, generally, its implementation requires little or no modification to existing wiring installations, although additional infrastructure may be required in some cases. Depending on whether the control is of an analogous or digital nature, luminaires are controlled either centrally as a group from a distribution box or central control location, or individually based on the use of programmed electronic control gears or drivers. An example of this method of dimming could be that at peak times the lighting will operate at 100 % luminous flux, with a reduction to 60 % during the quieter hours of the night.



A *Single phase switching with twilight sensor.*

Multi-step dimming

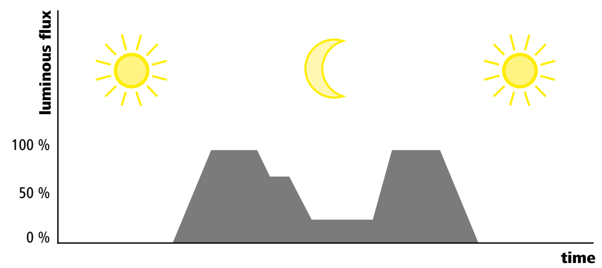
This method allows for the digital setting of the light output to several defined levels at various given times (B). The automatic cycle is determined based on a calculated 'virtual midnight', the variable midpoint between sunset and sunrise. One advantage of multi-step dimming over basic step dimming is that the light output can be more precisely matched to need and offers greater energy saving potential. Another advantage is that each luminaire can act independently as the functionality is programmed within each luminaire electronic control gear or driver. One disadvantage is that regulation based on a virtual midnight is not as precise as astronomical clock or twilight sensor control.



B *Single phase switching with twilight sensor.*

Linear dimming

This type of dimming is fluid rather than facilitated in immediate steps, meaning there is no significant change in luminous flux, but rather a gradual and visually comfortable change (C). Linear dimming is also not limited by defined levels, instead able to dim to any level on a percentile scale, although in streetlighting application it is still generally applied in multiple steps. It can be implemented according to defined times or based on real-time adaptation to need, such as to the presence of people or traffic, or according to weather conditions. This type of dimming can be used with individual luminaires or groups, with the functionality programmed both in the luminaires and the distribution box or some kind of central control software.



C *Single phase switching with twilight sensor.*

Modern lighting control methods allow for remote regulation and monitoring, which save time, energy and money.

COMMUNICATION

In order to facilitate control, there must be some method of communication between luminaires, distribution boxes and central control locations. This communication can be of a digital or analogous nature.

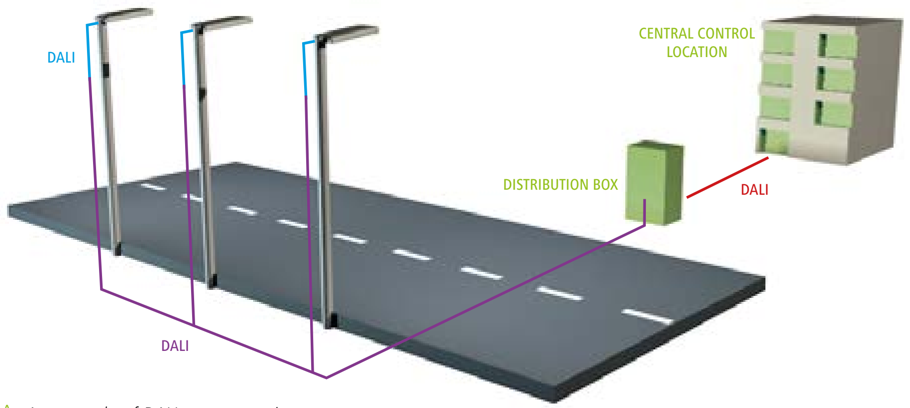
Standardly, cable-based communication is used, with an array of options available depending on the available or feasible electrical infrastructure, from single-phase, through multi-phase to the inclusion of additional cables or data cables. Then there is wireless control, which works on the basis of Wi-Fi communication.

1–10 V and DALI

1–10 V is a simple type of analogue control that regulates the luminous output of the luminaire by changing the control input voltage to the LEDs between 1 and 10 V DC. It is not possible to switch luminaires off using 1–10 V, so it is necessary to use an extra type of control such a phase switching, PowerLine control or Wi-Fi communication.

DALI (A) is a digital control protocol that uses twin-core non-polarity data cabling and allows a lighting system to be fully programmed based on timers, astronomical clocks, sensor input, lighting scenes, and pre-set and directly controlled light output levels. It enables independent control of individual luminaires or luminaire groups from a central location and/or several local points. DALI continuously monitors the system and provides real-time feedback about luminous output levels, energy consumption and faults, failures and their location, which saves time and reduces maintenance costs.

Both of these popular protocols are used extensively in interior applications. However, their use in streetlighting is somewhat limited by the fact that control lines only operate over short distances. 1–10 V lines can be a maximum of 150 m, and DALI lines 300 m, neither of which are feasible for streetlighting systems, which tend to cover large areas. For this reason, the protocols are generally used only for communication between the electronic control gear or driver and LEDs of the luminaire, and combined with other protocols used between the luminaires and distribution box.



A *An example of DALI communcation.*

It is possible to use DALI in some specific applications that cover a smaller area, such as petrol stations.

Lighting level regulation method: switching, step dimming, multi-step dimming and linear dimming.

Step 1: Communication between the central control location and individual distribution boxes can be done using the DALI protocol.

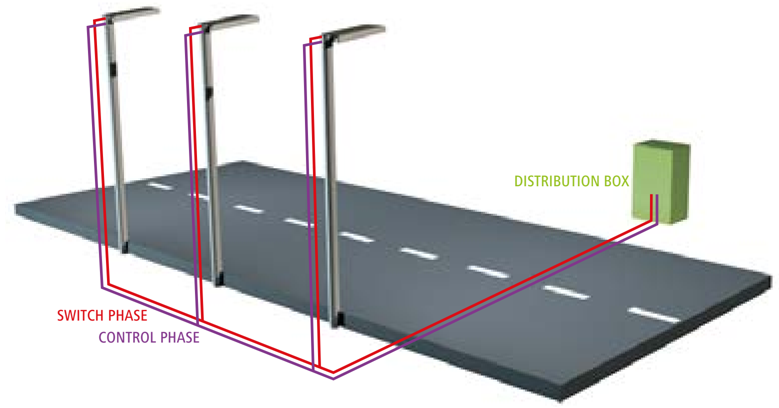
Step 2: Communication between the distribution box and luminaire electronic control gears or drivers is done using the DALI protocol.

Step 3: The electronic control gears or drivers control the luminous flux of the luminaires using the DALI protocol.

Phase switching

This analogue control method requires the use of two power lines as inputs to the luminaire control gears or LED drivers (B). The first line is referred to as the switch phase because it is used to switch the lighting on and off by switching the power on and off. The second line is used to provide further control and so referred to as the control phase. When power is fed to the switch phase, it is possible also to feed power to the control phase, which switches the lighting to a second mode, for example, to 50 % luminous flux. By stopping the current to the control phase, the lighting returns to 100 %. The control phase cannot be fed without simultaneous feeding of the switch phase. Phase switching is usually implemented centrally in a distribution box and can, therefore, work in combination with basic astronomical clock, timer or sensor control. This is a suitable method for renovating old lighting systems as older wiring installation often used four-cable electricity distribution.

Lighting level regulation method: switching, step dimming.



B *An example of phase switching.*

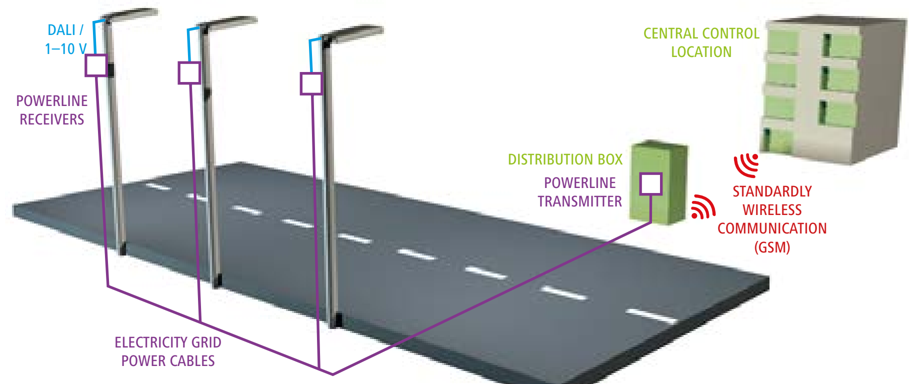
Step 1: The switch phase is used to turn the luminaires on and off.

Step 2: The control phase is used to reduce the luminous flux of the luminaires.

PowerLine communication

This is a type of control implemented using standard mains 230 V AC power lines and requires only a single phase (C). The communication is done using a carrier signal (control signal) that is sent along the standard mains voltage in small 'packets'. Additional devices are required to manage the communication at either end. It is possible to have several communication points within the same system, all controlled from a central location. Various dimming protocols can be used in this way, including DALI and 1–10 V, depending on the types of electronic control gear or driver used. The advantage of this type of control is that no additional infrastructure is needed because all communication is done via the standard mains power lines, which does not interfere with normal functionality.

Lighting level regulation method: switching, step dimming, multi-step dimming and linear dimming.



C *An example of PowerLine communication.*

Step 1: Communication between the central control location and individual distribution boxes is generally done using GSM wireless communication, although it is possible to use other protocols.

Step 2: Communication between the distribution box and luminaire electronic control gears or drivers is done directly along the power cables using PowerLine Communication transmitters and receivers.

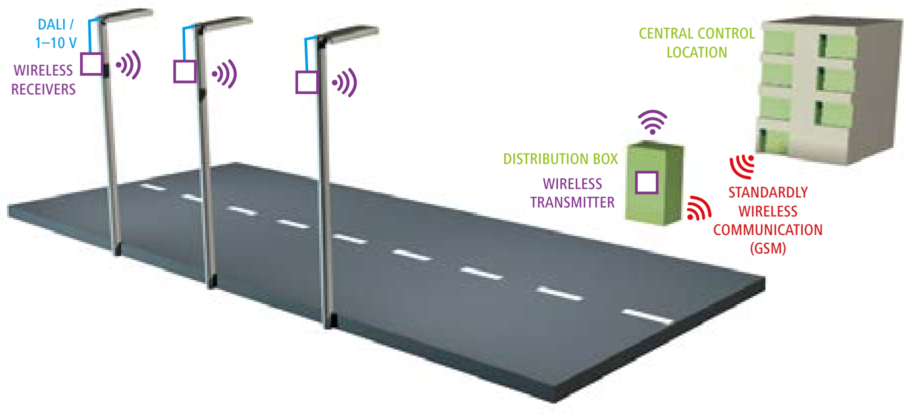
Step 3: The electronic control gears or drivers use 1–10 V or DALI to control the luminous flux of the luminaires.

Wireless control is not bound by electrical and infrastructural limitations, making it the most flexible control method available.

Wireless (Wi-Fi)

Wireless control is mostly used in locations where it is not possible or technically or financially viable to install additional electrical infrastructure or data cabling (D). All luminaires need to be equipped with a DALI or 1–10 V electronic control gear or driver and a wireless receiver that receives signals from a transmitter installed in the distribution box. The transmitter allows for management and monitoring over the internet from any location. All control is ultimately facilitated using comprehensive control software that enables switching, dimming and the setting of timers in addition to providing in-depth system feedback. One significant advantage of using wireless control is that the luminaires are able to communicate with each other, extending the range of the management system up to 1 km to create a large-scale network. This is in comparison to cable-based control, which is limited by the possible lengths of control lines to a few hundred metres.

Lighting level regulation method: switching, step dimming, multi-step dimming and linear dimming.



D *An example of Wi-Fi communication..*

Step 1 :Communication between the central control location and individual distribution boxes is generally done using GSM wireless communication, although it is possible to use other protocols.

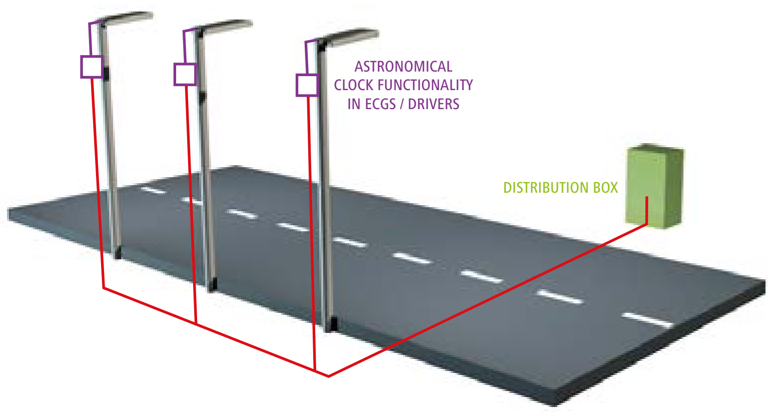
Step 2: Communication between the distribution box and luminaire electronic control gears or drivers is done using Wi-Fi.

Step 3: The electronic control gears or drivers control the luminous flux of the luminaires using the 1–10 V or DALI protocol.

Luminaire-based astronomical clock

Standard astronomical clock functionality is based in the distribution box and used simply for switching as mentioned a few paragraphs earlier (E). However, it is also possible to programme the same function in the electronic control gears or drivers of individual luminaires, and there is the added possibility of combining it with twilight sensors that can be applied to individual luminaires or to a master luminaire that controls a group. This method is advantageous because it does not require any additional communication infrastructure. However, functional parameters must be set before installation and cannot be changed later.

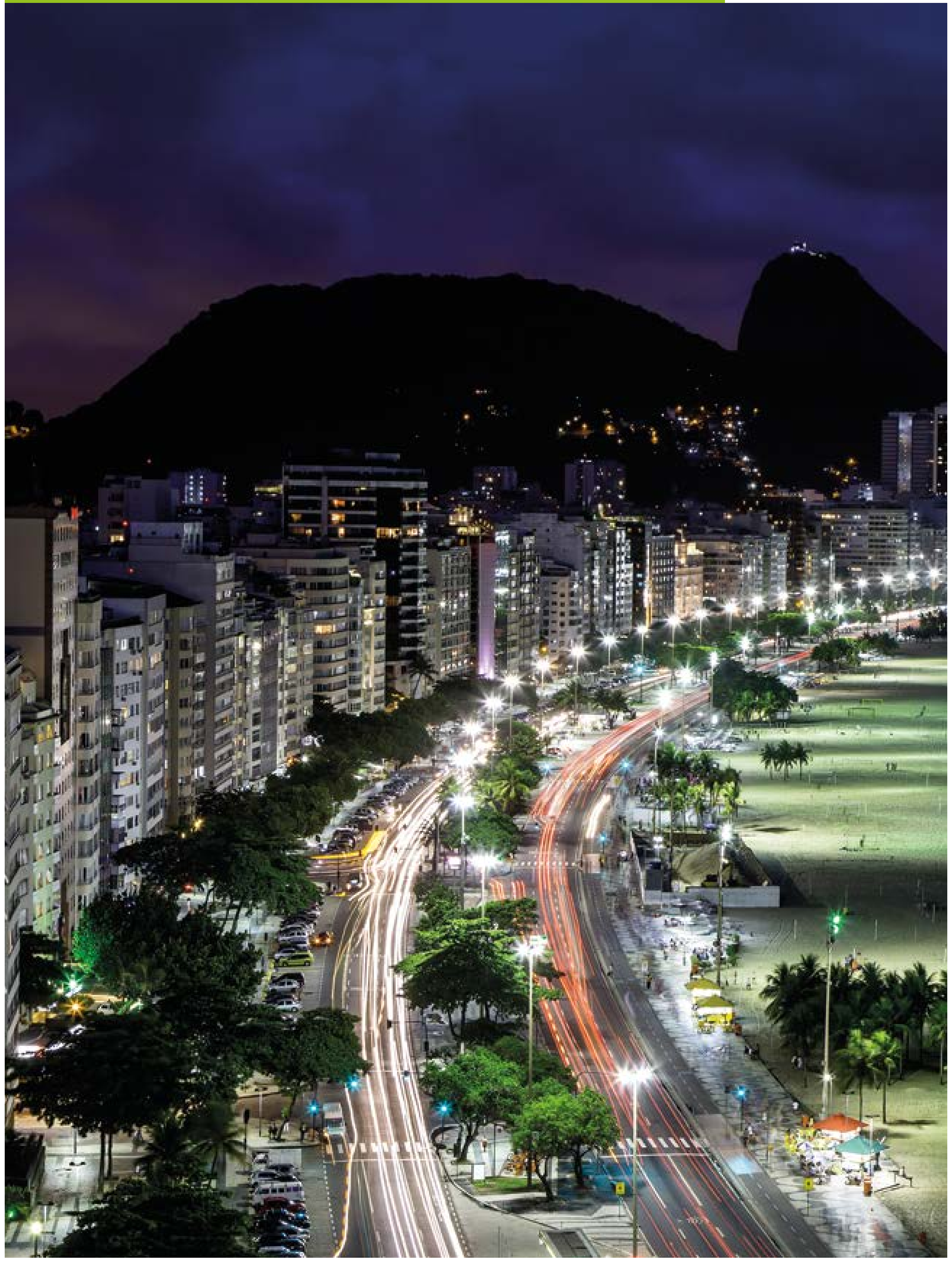
Lighting level regulation method: switching, step dimming and multi-step dimming.



E *An example of phase switching.*

Step 1: A standard single phase is used to power the luminaires.

Step 2: The astronomical clock functionality is programmed directly into the electronic control gears or drivers of each luminaire.



ESPRIT

Esprit is about making the ordinary into something extraordinary, about a sense of grace, humour and the ability to surprise, enriching our lives by bringing an element of the unfamiliar to our everyday environments. This is something our product designers know very well. They consciously push the boundaries of design when creating new luminaires, scorning stereotypes in favour of pure imagination. In this way, public lighting can take on an air of the artistic rather than the purely functional.

Street and urban lighting luminaires can take on a new and exceptional architectural role, sometimes by their extravagance and other times by their restraint. No other area of application offers such unique possibilities. Functionality ceases to be the sole criteria as it is joined in equal part by originality and innovation.

SLE understands the diversity of customer and solution requirements and offers only the most exceptional products with a futuristic soul and the ability to infuse a public space with a breath of fresh air.

There are no quantifiable criteria within the LQS for evaluating esprit as it is a highly subjective topic. However, there are several important elements we urge customers to consider in order that they make the most informed, and ultimately satisfying choice, about which luminaires to use. Firstly, consider the overall impression the luminaire and its intricacies make. Secondly, how does the luminaire fit into the space, both in terms of presence and how it ties in with or complements the surrounding environment. Thirdly, the surface finish, which is a fundamental part of our reaction to its presence; does it evoke the desired feelings and communicate the right qualities. Fourthly, consider the materials used and the luminaire's functionality, as these aspects determine the practicality and value of the product.

DELTA

A residential luminaire
by Anton Zetocha

Created to satisfy the requirements of the Multichip lens, this luminaire is designed with fluid lines that flow through the body to the end where it safely encases the silicone lens. Yet, the design is not only about aesthetics, as the dynamic shape is also optimised to resist adverse weather conditions and in turn increase the lifetime of the luminaire.

TWIST

A residential luminaire
by Patricia Verdeguer Coll

The main idea behind this concept is the integration of the Multichip lens into a neat body that does not only fulfil it's functional purpose, but also add an aesthetic value to environments such as residential areas, gardens and parks. To this end, the designer decided to incorporate the lens into the pole itself in a uniquely creative way. At first sight, the luminaire may not catch the eye due to its discreet style, but upon closer inspection will bring a sense of finesse and fun to passers-by.

EXCEPTIONALITY

SLE's ambition is to create smart lighting solutions that bring added value and well-being to our lives in addition to showing respect for the environment. To this end we act as a lighting solutions project platform, focused on connecting everyone involved in lighting in mutually beneficial collaboration under the umbrella of SLEs knowledge, tools and services. In this way, each participant can contribute their unique skill set towards a cooperative final solution of higher value and quality than could be achieved alone.

This chain of value is what sets SLE projects apart, acting as a simple and reliable framework upon which our partners can stand with confidence. Furthermore, we understand that a successful business strategy must be customer focused, and SLE's support enables partners to be just that, because we have the rest covered.

WHAT SETS IS APART

Our partners can come to us for exclusive products, full solution packages, comprehensive yet simple sales support and cutting-edge information, which together help us achieve the collective goal of putting the future of lighting into practice now to provide a better future and achieve business success.

Exclusive products
Our distinctive product portfolio offers cutting-edge products that are guaranteed to perfectly integrate with every solution we provide. And as each product it designed for specific applications, our partners can rely on finding the best fit for every lighting design and project. Furthermore, with the possibility of product customisation, both partners and customers are assured that every solution is truly specialised and therefore unique and worry-free.

Complete solution packages
Lighting can be complicated, especially considering the influx of new technologies, terminology and possibilities. This creates stress for both customers who do not necessarily understand their possibilities, and lighting professionals who must navigate a myriad of options to find the best solution. With this in mind, we offer a range of complete 'ready-made' solutions for every application, to keep things simple for everyone but never at the expense of quality or suitability. Each solution includes everything needed for the implementation and completion of each project and even comes with added benefits.

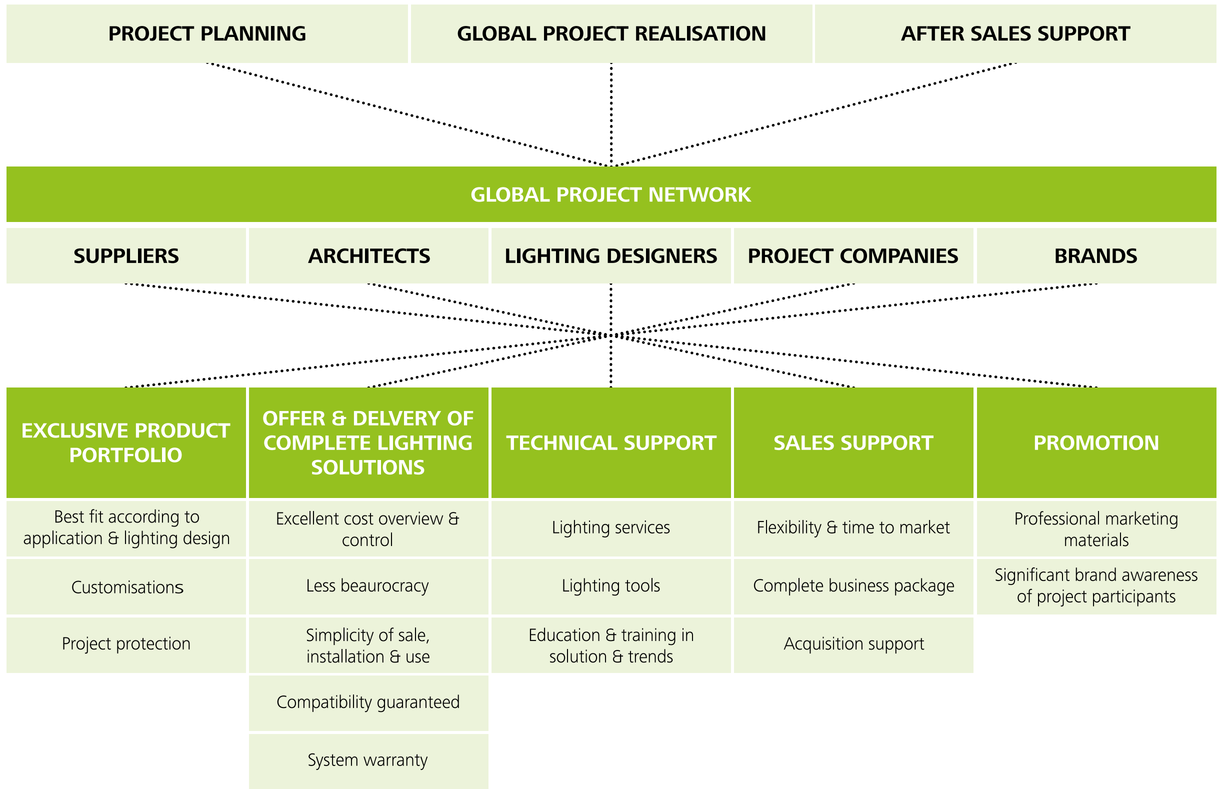
Moreover, as each solution is provided as a whole, full compatibility of all components is guaranteed, and the entire system falls under one straightforward warranty. To help partners communicate these solutions, we provide understandable and transparent information that makes it very easy for customers to grasp the options and make an informed choice. In this way, lighting suddenly becomes very simple.

Each complete solution package contains:

- Lighting services
  - Lighting audit
  - Luminaire selection
  - Definition of illumination
  - Lighting calculation
  - TCO calculation
  - Standard wiring design
  - Lighting measurement
  - Energy measurement
  - Customer presentation
- Luminaires
  - LED luminaires
  - Luminaire package and transport
- Support
  - Transport
  - Lighting installation
  - LMS adjustment
  - LMS training
  - Electrical installation approval
  - Recycling of old lighting installation materials

We tailor our services and support to current and future market needs, thereby increasing the effectiveness of every link in the value chain, from supply to end use

LIGHTING SOLUTION



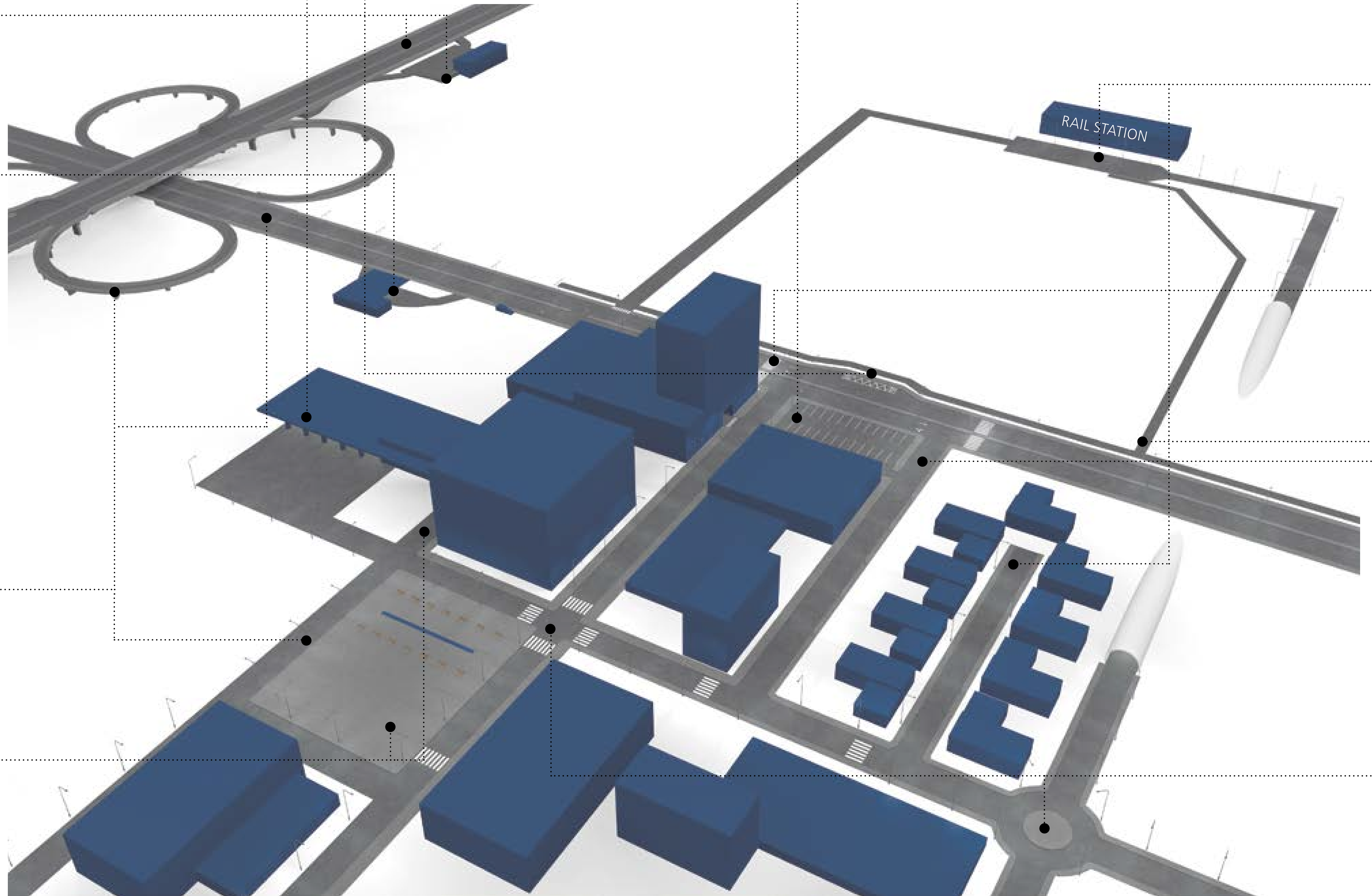
Sales support
Our partners' realisation is at the heart of our interests, which is why almost everything in the SLE value chain is useful for those on the front line. From technical support tools through product information to marketing materials and project promotion, we provide everything needed to achieve sales success. And once a sale has been made, we will also help with acquisition and financing, giving customers a name they can trust and taking the extra load off our partners. With such a complete business package, our partners will never be short of help in attracting customers and building a firm and long-term relationship with them.

Technical support
We have created a framework of clear and accessible knowledge, practical and theory-based support, and insights into the development of lighting through research. To achieve this, we eagerly follow the trends that are driving technological and ecological development in the global market and apply them to lighting and its influence on both humans and the environment. This knowledge is implemented both through our own lighting services and in the development of a number of specialised proprietary supportive tools for all involved in sales, project planning and implementation. These tools include the Lighting Quality Standard, described earlier in this publication, and its associated software tools LQS Composer and LQS Composer PRO, in addition to LIACS, Saving in 5 and the Right Light books, one of which you are reading right now. For more information about these tools and how they can help you, visit the SLE website.

Promotion
It is no fun doing the work and never getting any credit, which is often the case for the individuals and small companies involved in the provision of lighting solutions. We believe that everyone involved in a project should be given due recognition. All partners involved in our projects are included in related promotion. This strengthens both the presence of truly skilled professionals on the global lighting scene and the network of support and collaboration that will drive the success of all.

www.sleprojects.com

LIGHTING
IN THE STREET & URBAN



Motorways are the veins of our countries
and have the highest lighting requirements
in order to assure maximum safety.

MOTORWAYS & REST AREAS

Motorways are not usuallly illuminated, but the sections of these high-speed routes that pass within town and city borders are. When planning the illumination of routes with fast moving vehicles, it is vital to create lighting conditions that enable drivers to easily and rapidly recognise other vehicles, traffic signs and markings, and dangerous situations or obstacles from a distance sufficient to allow for necessary reactions.

Motorways

Inter-urban motorways usually fall under the ME1 and ME2 classification according to the EN 13201-1 standard, which place the highest requirements on public lighting system design and stipulate the provision of a road surface luminance of 2 cd/m^2 or 1.5 cd/m^2 respectively. Along with more demanding lighting needs, these busy and dangerous roads also necessitate that sufficient care be taken in the directing of the light so as to appropriately illuminate not only the road, but also the surrounding area to ensure visual comfort, and to minimise light pollution and energy consumption.

How the luminaires are positioned depends on both the road's construction and available finances. In the case that both carriageways are separated by a narrow area large enough for the mounting of luminaires, it can be an ideal solution to mount two independently directed luminaires on a single pole in such a way that they illuminate to both sides. However, if the carriageways consist of four or more lanes, this solution cannot provide sufficient and suitable illumination. In the case that this solution is not feasible, due to the lack of a central divide, the divide being too large, or their being many lanes in either carriageway, then it is necessary to use a more complex and costly design in which luminaires are mounted on both sides of the road. As twice as many mounting poles are needed, twice the electrical infrastructure is also needed and it is often then case, as a result of financial restrictions, that the less expensive first option of central mounting is preferred. Whatever positioning is chosen, to ensure appropriate lighting uniformity and minimise glare, it is recommended to use luminaires with asymmetric light distribution mounted at heights between 12 m and 16 m, at 30 m to 50 m intervals. However, to provide ideal lighting, each application must be assessed on its own merit, and these recommendations may or may not be optimal, necessitating that the lighting designer choose the best rather than most common solution.

Another concern with such lighting systems is their high energy consumption, as the light sources must be very powerful to ensure adequate road surface luminance. There are ways by which to reduce energy consumption using some kind of lighting regulation, such as automatic switching based on actual ambient light levels rather than set times. However, we do not recommend the implementation of dimming on motorways for reasons of safety due to the consistently high speeds at which vehicles travel and the fact that they are in constant use, even if sometimes quieter. Another way to improve safety is to use LED luminaires that emit cool white light that is proven to heighten alertness and concentration, helping to minimise the effects of monotonous driving conditions and the incidence of microsleep and related accidents.

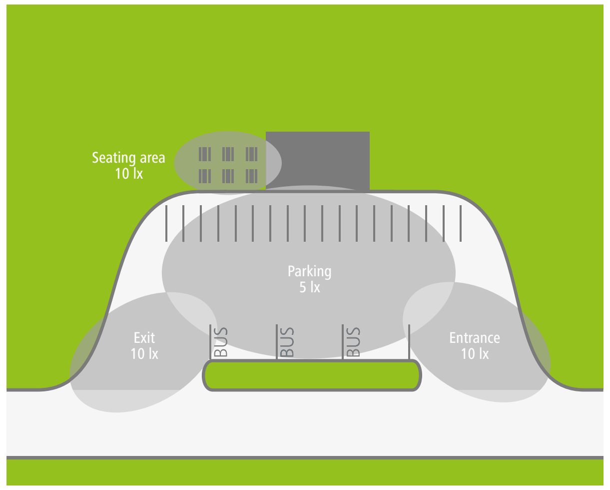
Rest areas are a vital component of our road systems as they allow drivers to safely and comfortably take the breaks necessary to ensure their continued safety.

Rest areas

You often find rest areas located next to long stretches of unilluminated motorway. The lighting of such places requires a careful balance of factors, as it must allow drivers to recognise the facility from a distance while not compromising their visual acuity and comfort.

What is defined as a rest area ranges from spaces off the main stretch of road designated for parking and relaxation, to those comprised of car park, toilet facility, petrol station and restaurant zones (A). Each of these different zones has its own lighting requirements falling under different standards, with petrol stations covered separately in this book and restaurants discussed in detail in the Hotel and Gastro book of the Right Light series. Relaxation zones usually come under the S or A classification of the EN 13201-1 road lighting standard, with parking areas also covered less specifically by the EN 12464-2 standard for outdoor workplaces. Regardless of the standard used, the main criteria for assessing the required lighting parameters is traffic flow and pedestrian frequency. For such areas, an illuminance of 5–10 lx is stipulated, depending on usage.

One other thing to bear in mind is that the choice of luminaire type and their subsequent positioning is quite free, although standard street luminaires are used predominantly, sometimes with supplementary use of projectors, decorative luminaires, bollards and backlit billboards when appropriate. Whatever the overall lighting design chosen, it is important to choose luminaires that direct light only where needed and not into the night sky or excessively into nearby vegetation or nature areas so at to protect the night environment and natural ecosystems. Another way by which to protect the environment is to use lighting management to control the lighting according to need so that at quieter times the luminaires can be dimmed, resulting in reduced power consumption.



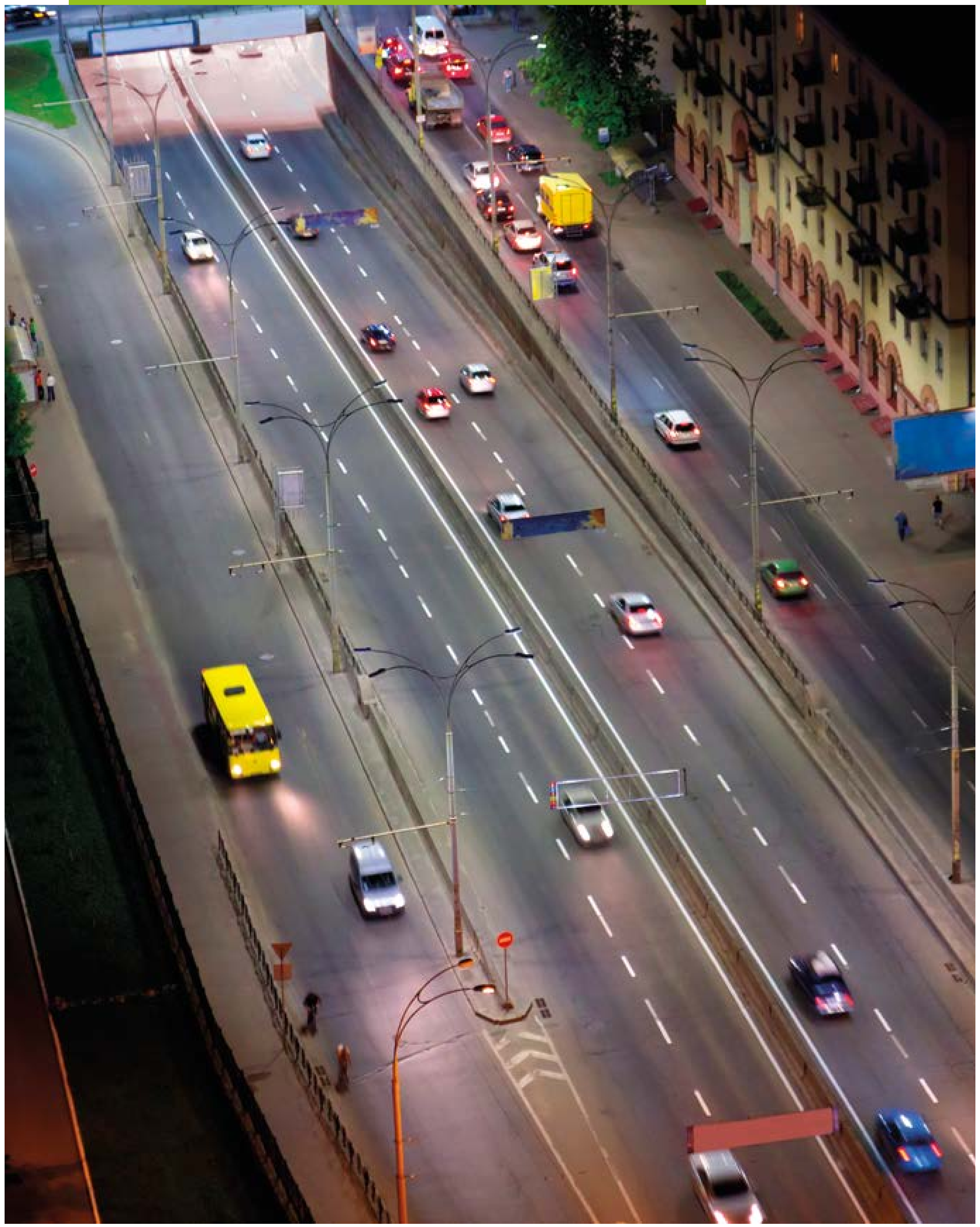
A *Larger rest areas consist of several different zones with specific lighting needs. There are no standards covering picnic areas, but we recommend a luminance of 10 lx.*

These are the roads that shape our everyday lives and so need to be appropriately illuminated to ensure our safety.

MAIN ROADS, MINOR ROADS & SLIP ROADS

These are the most used roads within cities and towns with the exception of residential and access routes. On such roads, drivers must often share the space with cyclists and pedestrians, and as a result there are speed limit restrictions of 50 km/h or 30 mph, or lower if deemed necessary in highly built-up or complex areas.

This type of mixed traffic is more closely defined in the EN 13201-1 standard, which specifies several classes of illumination depending on whether or not there are segregated areas for motor vehicles, cyclists and pedestrians. In the case that all road users will use the same space, only one lighting system is required. In the case that there are segregated zones for different types of road user, pavements, bike lanes and carriageways must be equipped with their own specialised lighting.



When designing the lighting for a shared-use road, there are several factors to keep in mind as such roads tend to be located in towns and rural areas, and the visual tasks performed by drivers, cyclists and pedestrians are complex. In addition to watching the road and other road users, there are a myriad of other elements requiring attention, for example parked vehicles, advertisement billboards and message boards in the field of vision and cyclists, pedestrians and obstacles. There are also constructional elements that require attention, including possible road changes designed to ease congestion, as well as junctions and their frequency. All of these factors together define the difficulty of the visual task at each given point on the route, the complexity of the visual field and the surrounding luminance. Within the EN 13201-1 standard, there are a range of lighting classes that can be determined according to accurate assessment of these many factors, and which better define particular lighting requirements.

For main and minor roads, the standard recommends the application of ME classification, specifically ME2 to ME5, which are determined on the basis of whether the prevalent weather conditions in a given area result in mainly wet or dry road surfaces, as well as the division of traffic flow in different direction, junctions types and average expected traffic flow. Following these criteria, the standard sets out the following minimum requirements:

- An average road surface luminance [L_{av}] of 0.5–1 cd/m²,
- An overall uniformity of road surface luminance [U_o] of 0.15 for predominantly wet roads and 0.4 for predominantly dry roads,
- A longitudinal uniformity of road surface luminance along a driving lane [U_l] of 0.4 to 0.7 cd/m²,
- A glare threshold increment [T_l] of 15 % maximum,
- A surround ratio of illumination on a carriageway [SR] of 0.5.

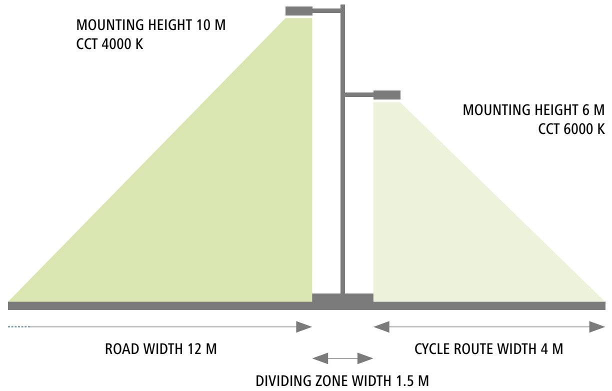
Where there are conflict areas on traffic routes, such as complex junctions or roundabouts, CE road classification applies, and accordingly the standard stipulates the following minimum requirements:

- A minimum average vertical illuminance [$E_{v,av}$] of 7.5–20 lx,
- An overall uniformity of road surface luminance [U_o] of 0.4.

However, road luminance also affects the illumination of adjacent areas, like cycle paths, pavements and foliage, and it is important to bear this in mind when designing the lighting system.

A suitable solution for this road type can be obtained by using pole-mounted luminaires installed at a height between 6 and 10 m, or 8–10 m for ring road and slip road application. The spacing between luminaires ranges between 20 and 50 m, with the best lighting uniformity achieved when the spacing is in the region of 30 m. Luminaires can be installed along one or both sides of a road. Although the second option is more technically and financially demanding as well as requiring additional electrical infrastructure, it does provide better luminance levels and uniformities.

In the case that multi-lane carriageways have adjacent bike lanes or pavements, the road lighting should be supplemented by additional pole-top luminaires mounted at lower heights and that use light sources emitting a distinct CCT to support the visual differentiation of the individual zones (A).



A A multi-lane carriageway with adjacent bike lane. Note how independent lighting has been provided for both areas, providing optimal illumination for each and aiding visual differentiation.

It is of special importance that spaces shared by vehicles and pedestrians are adequately lit to minimise the risk of accidents.

ACCESS ROADS, RESIDENTIAL ROADS & TRAFFIC CALMED ZONES

These roads include those found in suburban areas and residential zones, and include construction site entrance routes and town or city centre zones with restrictions on motor vehicle access. The speed limit is 30 km/h and, as such roads rarely have separate pavements, is for the use of motor vehicles as well as cyclists and pedestrians, highlighting the need for added emphasis to be placed on safety.

The lighting provided in these applications must not only illuminate the road, but also adjacent areas to ensure visual comfort and the safety of pedestrians entering the area. To achieve optimal recognition and visibility of pedestrians, it is necessary to provide sufficient vertical illumination, which simultaneously acts to deter and reduce crime by improving facial recognition and the observation of people from a distance. It is also important that the lighting be designed to minimise both glare and light pollution.

According to the EN 13201-1 standard, these types of road fall under the S classification, and, therefore require the following:

- An average illuminance [E_{av}] of 2–15 lx,
- A minimum maintained illuminance [E_{min}] of 0.6–5 lx
- The lighting uniformity is ensured by keeping the average illuminance [E_{av}] lower than 1.5 times the lowest illuminance [E_{min}] value required for the relevant road class.

Since these lighting systems are mainly yards and gardens, residential zones frequented by playing children and task-specific areas in addition to the roads, the colour rendering provided by the light sources should be higher than CRI 70. It is also beneficial to use lighting that emits a warmer coloured white light that feels safe and comfortable. To ensure optimal illumination and lighting uniformity, it is advised that luminaires be mounted at a height of 5–8 m and spaced 20–40 m from each other.

Access roads.

Residential roads.

Traffic calmed zones.

Queuing and pick-up areas.

The most dangerous parts of our roads, proper illumination can have a significant impact on our safety.

JUNCTIONS, CROSSROADS & ROUNDABOUTS

It is easy to lose your way in an unknown area and even in a more familiar place if it is busy, especially if signs are poorly illuminated and junctions shrouded in shadow. This can result in drivers getting confused, slowing down and stalling other traffic, showing less attention to the road as they search for signs, and even erratic or dangerous driving such as sudden braking or turning without slowing sufficiently or indicating. For this reason, it is important than signs, junctions and any other navigational elements of the road are properly illuminated.

A good example of junction illumination.

Junctions and crossroads

Covered by the EN 13201-1 standard under the CE classification, junctions and crossroads require a minimum lighting uniformity of 0.4 and, depending on traffic flow, an illuminance of 7.5–50 lx. It is also to be noted that the illuminance at the junction or crossroad must be one class higher than that of approach roads in order that they are clearly visible to drivers from a distance, to allow them time to react and prepare for slowing, stopping and turning. As junctions and crossroads are particularly dangerous sections of a road network, it is important to provide suitable vertical illumination to enable easy recognition of pedestrians, cyclists and other road users as well as clear visibility of road signs from an appropriate distance.

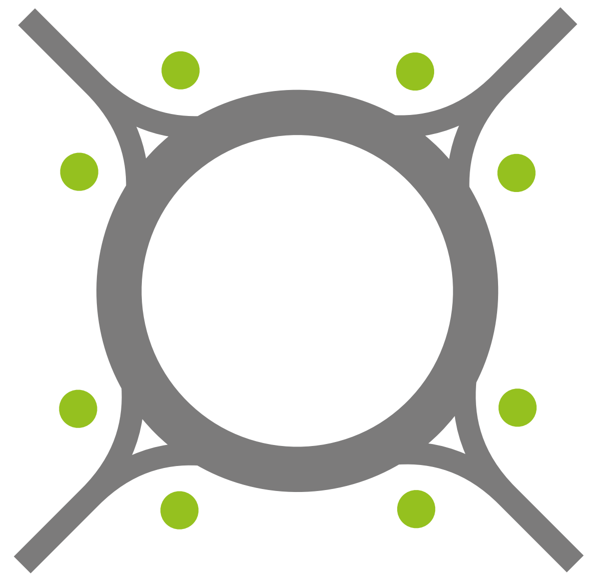
To achieve the desired lighting conditions, it is best to position luminaire poles on the corners of junctions and crossroads where road users slow, stop and turn in accordance with traffic control and navigation signage. Furthermore, it is crucial in all cases to minimise the incidence of glare, which could be particularly detrimental to safety and easy navigation by reducing visibility of road signs and other road users.

Roundabouts

Roundabouts are circular junctions that allow for continuous or near-continuous flow of traffic in one direction. They are used to ease traffic flow and simplify traffic movement, which in turn increases safety. In addition, roundabouts remove the need to make left (or right in the UK) turns out of standard junctions, a major cause of traffic collisions.

The illumination of roundabouts follows the same principles as that of other junctions but offers two luminaire positioning possibilities. The first is to place a dedicated lighting installation consisting of several luminaires on the central island of the roundabout to provide the require lighting around its entire circumference. This option is especially suitable for smaller roundabouts that can be properly illuminated from one point. To reduce the number of mounting poles needed and their wiring, it is sometimes suitable to use fewer poles and higher-powered luminaires.

The second possibility is to place poles all around the circumference of the roundabout (A). This option is used in cases where it is not possible to adequately illuminate the full area from one point or to install high mounting poles on the central island. This method requires more poles and wiring but comes with the advantage that additional luminaires can be mounted on some poles to illuminate entry and exit points. Whichever method is used, the luminous intensity needs to be the same at all entry and exit points as at the roundabout itself.



A *A particularly suitable positioning of luminaires for a roundabout.*

Crossings are the places where pedestrians take priority over vehicle traffic, and need to be illuminated as such.

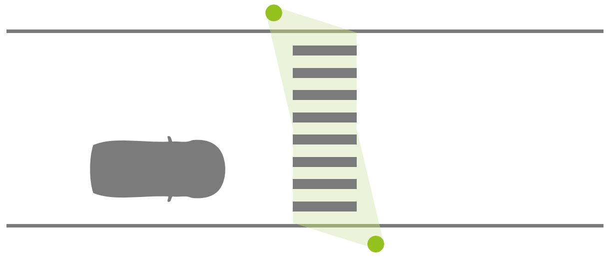
PEDESTRIAN & CYCLE CROSSINGS

Pedestrian and cycle crossings are road sections where all road users must slow down and give way to those crossing. In order for drivers to react promptly, such areas must be clearly visible by means of being illuminated to a higher level than other sections of the road.

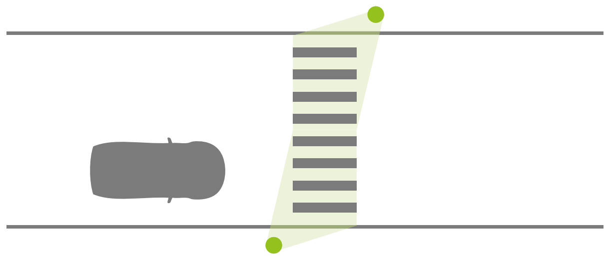
However, the key is to illuminate crossing pedestrians and cyclists rather than the crossing itself. To achieve this, emphasis should be placed on the provision of sufficient vertical rather than standard horizontal illumination.

The EN 13201-1 standard, annex B, states that a lighting system can be designed to make those crossing the road more visible using either negative (A) or positive (B) contrast.

We recommend using positive contrast when illuminating those crossing the road, making them look like illuminated objects against a dark background. This is because vertical illumination of the person increases with the approach of vehicles and light from their headlights, which in the case of using positive contrast increases the contrast between the person and their background, whereas in the case of the using negative contrast, decreases the contrast and, therefore, ease or recognition.



A Negative contrast means silhouetting the pedestrian against their background by directing light on them toward the traffic, potentially causing glare.



B Positive contrast brightly illuminates the pedestrian against a relatively darker background. This is achieved by using a higher illuminance in the area of the crossing, which is directed so as the cast vertical illumination on the pedestrian in the same direction as traffic movement.

To achieve positive contrast, it is best to use luminaires with asymmetric light distribution that provide good vertical illumination of crossing pedestrians and cyclists in the direction of approaching traffic. The use of asymmetric distribution also minimises the incidence of dazzling glare for drivers. Suitable contrast requires the use of a minimum luminance ratio of 1:3, where those crossing are perceived as at least three time brighter than their background. However, the optimal ratio for each application depends on the road class. Furthermore, this contrast must be maintained across the entire road, which can be achieved by locating the luminaire mounting poles approximately 4 m from the centre of the crossing zone. In addition to illumination of the crossing zone, it is important to appropriately illuminate the adjacent pavement area. Luminance of the area 1 m from the edge of the pavement should be no less than twice that of the road, a ratio of 1:2.

Another technique that aids in rapid and easy recognition of waiting or crossing pedestrians and cyclists is the use light sources emitting different colour temperatures. For example, if the road is illuminated with warm white light, the crossing should be illuminated with cooler light or vice versa. This creates clear optical differentiation of the crossing zone and the road and attracts driver attention more easily than if a single colour temperature were employed throughout.

Users of cycle paths do not always have their own light, making it important to suitably illuminate these areas to ensure safety and security.

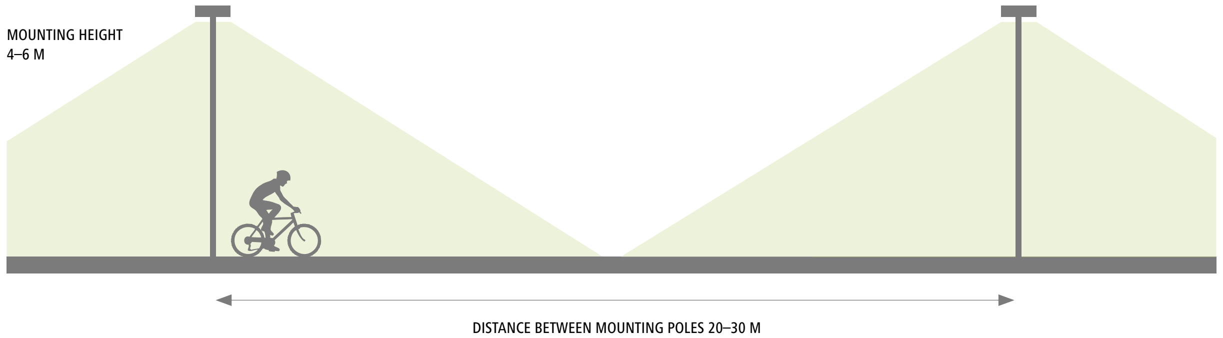
CYCLE PATHS

Cycling is a common pastime, means of exercise and an environmentally friendly method of getting around. For this reason, many countries have invested much in the development of comprehensive cycling networks around towns and cities. Those that run alongside roads are dealt with in a previous chapter. In this chapter, we will focus on the correct illumination of those cycles paths that run independently of roads, possibly nearby to parks or through busy town or city centre areas.

Many municipalities and individuals see cycling as part of the answer to the drive to reduce traffic flow and pollution in congested urban areas. For this reason, the number of cyclists continues to rise, as do the incidence of accidents. To maximise safety and minimise the occurrence of any type of fall or collision, it is vital that bike paths be well illuminated. This aids in cyclist's recognition of other cyclists as well as obstacles and the route in front of them.

The illumination of bike paths is covered by the EN 13201-1 standard, which places them under S or A classification. According to the S classification, horizontal illuminance should range from 2 to 15 lx, depending on the number of cyclists usually using the route, with minimum values of 0.6–5 lx. For those paths or sections of paths that necessitate easy facial recognition, the A class is used, which defines hemispherical illuminance instead. Here, again based on traffic, the illuminance level should be between 1 and 5 lx with a lighting uniformity of no less than 0.15.

As bike paths tend to be narrow, it is appropriate to use luminaires mounted at relatively low heights along one side of the route, which allows for the use of low-power light sources. Optimal mounting heights range from 4 to 6 m with spacing of between 20 and 30 m (A).



A *The most commonly used solution for cycle path illumination.*

Illumination of our public spaces enables us to enjoy them even in the darker hours.

PEDESTRIAN ZONES, PUBLIC SQUARES & PATHS

Pedestrian zone, public square and pavement lighting systems must fulfil two basic requirements: facilitating the safety of pedestrians and enhancing the aesthetic value of the areas in which they are installed.

Pedestrian zones & public squares

In terms of safety, the main functionality of the lighting is to afford pedestrians suitable visual acuity to easily recognise obstacles and discern and assess the presence and approach other pedestrians from an appropriate distance. To this end, it is important to provide both adequate levels of horizontal and vertical illumination.

The aesthetic element of the lighting is particularly relevant to pedestrian zones and public squares, which usually permit limited or no access to motor vehicle traffic. In town and city centres, the lighting must take on a strongly emotive role by being suited to the architecture, history and culture of the place. Historical areas are best served by more decorative luminaires that are reminiscent of the era of building construction and a warmer white light that evokes a pleasant, cosy and homely feeling. On the other hand, newly constructed areas benefit from modern luminaires and a cooler light colour that gives a sense of novelty, airiness and freshness.

According to the EN 13201-1 standard, these areas are covered by the S and ES classes. The S class defines horizontal illuminance values of 2–15 lx, depending on the specific classification and requirements of each area, with the S class ranging from S1–6. In all cases, the lighting uniformity should not fall below 0.6.

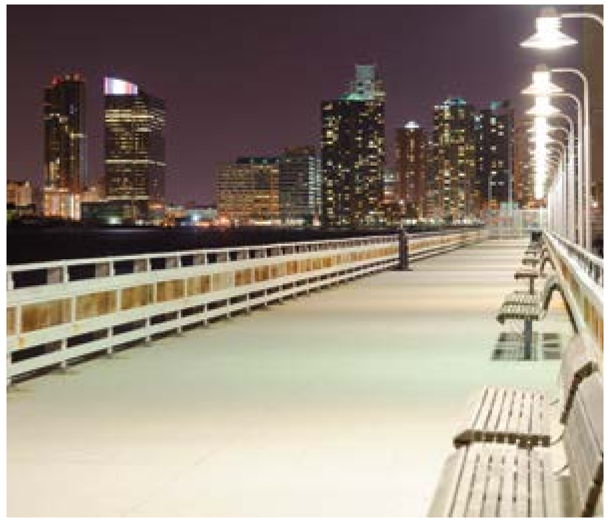
In areas where crime prevention and facial recognition are central factors in the lighting design, it is better to use the ES classification, which defines a semi-cylindrical illuminance of 0.5–10 lx.

Although street and urban lighting is predominantly provided by pole-mounted luminaires, in such spaces and pedestrian zones and public squares and even some pavements, it is also suitable to use bollard lighting and luminaires mounted in the ground to reinforce route navigation, spatial differentiation and the character of the area. As these luminaires are easier to gain access to than pole-mounted ones, it is important that they are vandal-proof. Furthermore, in such spaces, it is recommended to choose light sources with the highest CRI possible.

Paths

Often found weaving through parks and between villages, paths take us beyond main urban areas and routes. As a result, the lighting design must pay special attention to crime prevention and safety. Although the lighting requirements of paths are much the same as those for pedestrian zones and public squares, falling under S and ES classification, attention should be focused mainly on safety and only after on aesthetics. Similarly to the lighting of cycle paths, it is best to use pole-mounted luminaires along one side of the path, or both if it is wider. The luminaires should be mounted at heights between 4 and 6 m at intervals of 20–30 m. It is also important to illuminate adjoining areas to improve safety, feelings of security and aesthetic appeal by minimising areas of shadow.

Appropriate illumination makes even tree-lined parks feel open and safe during the night hours by minimising areas of shadow.



With the right light, even more remote areas of towns and cities can be safe and pleasant places to spend time in the evening.

Proper illumination makes safe navigation of parking areas easy and minimises the risk of pedestrian accidents.

OUTDOOR PARKING

Outdoor car parks are often located next to larger buildings, outside of residential areas, near shopping and commercial centres and on the outskirts of larger towns and cities. Such areas tend to be reasonably quiet with little traffic or pedestrian flow and, as a result, more likely to be the scene of criminal activity. To this end, it is vital that the illumination make the area feel open, minimises dark corners and enables clear recognition of vehicles and people from a distance.

It is also important that auxiliary areas, for example, access routes, barriers, ticket dispensers and exits, are well lit to ensure the easy and safe navigation of vehicles and pedestrians.

Lighting requirements for car parks are covered by two standards: the EN 12464-2 relating to outdoor workplaces, and the EN 13201-1 related to road lighting, under which such areas fall under S classification. Depending on traffic type and flow, the luminous intensity value stipulated for car parks ranges between 3 lx and 20 lx. As car parks are used by pedestrians and require the performance of complex tasks such as reversing in unclear situations, it is of crucial importance that adequate vertical illumination is provided by the lighting system. This is also a key factor in the effectiveness of surveillance monitoring, as good vertical illumination enables clearer recording of activity and identification of faces and vehicle registration plates.

There are two possibilities for illuminating car parks. The first utilises a large number of low-power luminaires mounted at heights between 4 m and 8 m, which is considered more aesthetically pleasing. This method allows for the use of existing car park or street lighting. The second possibility is to use fewer high-powered luminaires mounted at heights between 12 m and 20 m, which provides a more uniform light distribution. If appropriate, it is possible to mount several differently directed luminaires on one mounting pole, which minimises the expense of purchasing and installing poles and associated electrical infrastructure.

Other considerations to bear in mind are the minimisation of light pollution and energy consumption, both of which can be greatly improved if factored into the lighting design from the beginning. Light pollution can be controlled by the use of suitable luminaire optics that direct the light where needed and not into the sky, onto adjacent properties or through the windows of nearby buildings. And in terms of energy consumption, such areas are ideal for the application of dimming as they are often less frequently used during the quieter hours of the night or not at all after closing hours, meaning that illumination requirements are lower while still ensuring necessary visual acuity and safety.

A small car park requires few luminaires, sometimes only one, to provide sufficient illumination.

In some cases, a single luminaire per pole, mounted at a lower height, is more suitable.

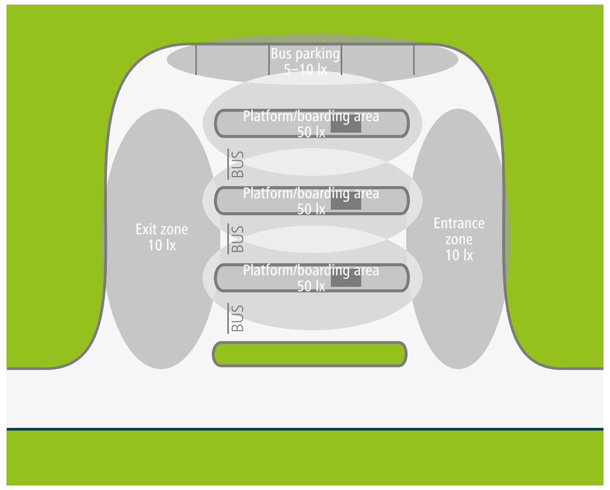
In larger car parks, it is better to mount multiple luminaires on each pole and at higher mounting heights. This reduces the infrastructure required.

A fundamental factor in the continued use or uptake of public transportation is the provision of a safe and comfortable environment both on the vehicle, and importantly, at places where we wait.

BUS STATIONS & STOPS

Even though we love the comfort of cars, public transport is still widely used, especially in urban areas where it is often the easiest and most effective way to get around. In addition, there is extra emphasis on the use of public transport as governments try to drive down traffic-related pollution and congestion in our towns and cities.

A fundamental factor in the continued use or uptake of public transportation is the provision of a safe and comfortable environment both on the vehicle, and importantly, at places where we wait. By improving the lighting at bus stops and stations, it is possible to have a profoundly positive effect on the perception of public transportation and passengers' feelings of safety, security and comfort. In all cases, the lighting must aid the bus driver in safely and easily navigating the environment and the required level of illumination and other parameters are determined according to standards and the type of area, road or situation.



A *Bus stations consist of different zones with their own lighting needs.*

Bus stations

Key to the safety and security of a bus station is that waiting and alighting passengers can easily see all that is happening around them, wait comfortably, read timetables, identify their surroundings and any obstacles or people in the area and recognise colours. This will ensure that the environment is pleasant and help to minimise crime as there will be no dark corners for lurking, and everyone will be able to see others approaching from a distance and to assess their intentions. In high crime areas, it may be beneficial to increase the illumination level above that required by standards to act as a further deterrent to criminal activity.

The EN 12464-2 standard stipulates the provision of 50 lx for areas where passengers board or alight vehicles, where pedestrians walk and where vehicles turn (A). Also, as such areas are partially or entirely open to the elements, luminaires must have an IP rating suitable for exterior use and have a high IK rating or be classified as vandal-proof.

Bus shelters

The lighting of bus shelters should be designed to illuminate the whole bus stop and make it easy to read timetables, as well as to adequately illuminate the area in front of the shelter so that those waiting can be easily seen from a distance. It is also important that shelters be fully illuminated within to deter undesirable and criminal activity. In this case, due attention must be paid to vertical illumination that aids in the recognition of figures and faces, as well as vertical surfaces. However, the lighting cannot be allowed to glare passing motorists and approaching bus drivers. Special attention needs to be paid to the illumination of bus stops in extra-urban areas where there may be little or no streetlighting in nearby, so that those waiting or alighting can be clearly seen by passing vehicles and accidents avoided.

Often, shelter lighting is connected to the same lighting installation network as the general streetlighting. In some cases, there may be additional advertising boards although they alone cannot provide sufficient illumination and need to be supplemented. As bus stops and shelters tend to be found on pavements, their lighting must comply with the EN 13201 standard, which requires the lighting intensity depend on the class of pavement and of the adjacent road. This means that lighting intensity levels will range between 7.5 lx and 20 lx. The same applies to bus stops without shelters, which are usually illuminated by the general streetlighting. If there is no luminaire within close enough proximity, it may be necessary to add another, or move a current one closer to the bus stop sign.

Proper illumination of petrol stations will attract customers and aid their safe navigation to and within the area.

PETROL STATIONS

Petrol stations are a necessary part of road and motorway infrastructures. Their proper illumination will not only reinforce the brand but will, importantly, attract customers and aid their safe navigation to and within the area.

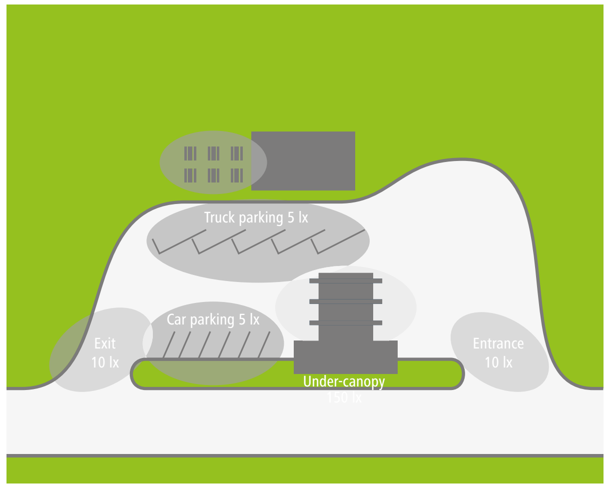
Lighting requirements for petrol stations are covered in the EN 12464-2 and EN 13201-1 standards, according to which the exterior area is divided into several different zones with different needs (A).

Firstly, there are the entrance and exit zones. Appropriate illumination of these areas is of special importance due to their connection to roads and motorways where other vehicles are travelling at high speeds. For this reason, drivers need to see the petrol station from an adequate distance to be able to safely react, slow down (sometimes from speeds well over 100 km/h to 0 km/h) and manoeuvre. Drivers also need to see other cars braking in front of them on entry to the forecourt as other vehicles may be waiting to access fuel pumps. Exit lighting must facilitate recognition and assessment of the speed of vehicles on the road they wish to enter. It is also important that exiting drivers clearly see any other vehicles or pedestrians in their route so as to avoid accidents. The EN 12461-2 standard stipulates that entrance and exits areas have an illuminance of 20 lx when located in darker suburban or rural areas, and 50 lx when located in brighter urban areas. In all cases, the lighting uniformity should be no less than 0.4.

However, the primary area of any petrol station is that under the canopy where the fuel pumps are found. Provision of adequate illumination is vital to the safety of drivers filling their cars and those walking to and from the shop or rest areas. As fuel pump displays are usually vertical, it is important to provide sufficient vertical illumination. This is also beneficial as it aids easy recognition of other people in the area, promoting feelings of security. Under-canopy lighting should have a higher intensity than surrounding areas so as to mitigate unnecessary adaptation of drivers' eyes to changes in brightness, as the shop front and interior are certainly illuminated to a much higher level than forecourts and car parks. Here, a minimum illuminance of 150 lx and a lighting uniformity of 0.4 is required. As the lighting in this area also affects thaeperception of the shop area, it is beneficial to use light sources with high CRI values.

For information about the most suitable illumination for the shop area, please take a look at the Retail book of the Right Light series.

The final area to think about is the car park, which specifically falls under the EN 13201-1 standard. Here the illuminance must be 5 lx and the lighting uniformity no less than 0.25. You can find more information about lighting for outdoor parking areas in the chapter covering this topic.



A Petrol stations are divided into entrance, exit, parking, filling, shopping and pedestrian zones, all of which have specific lighting requirements.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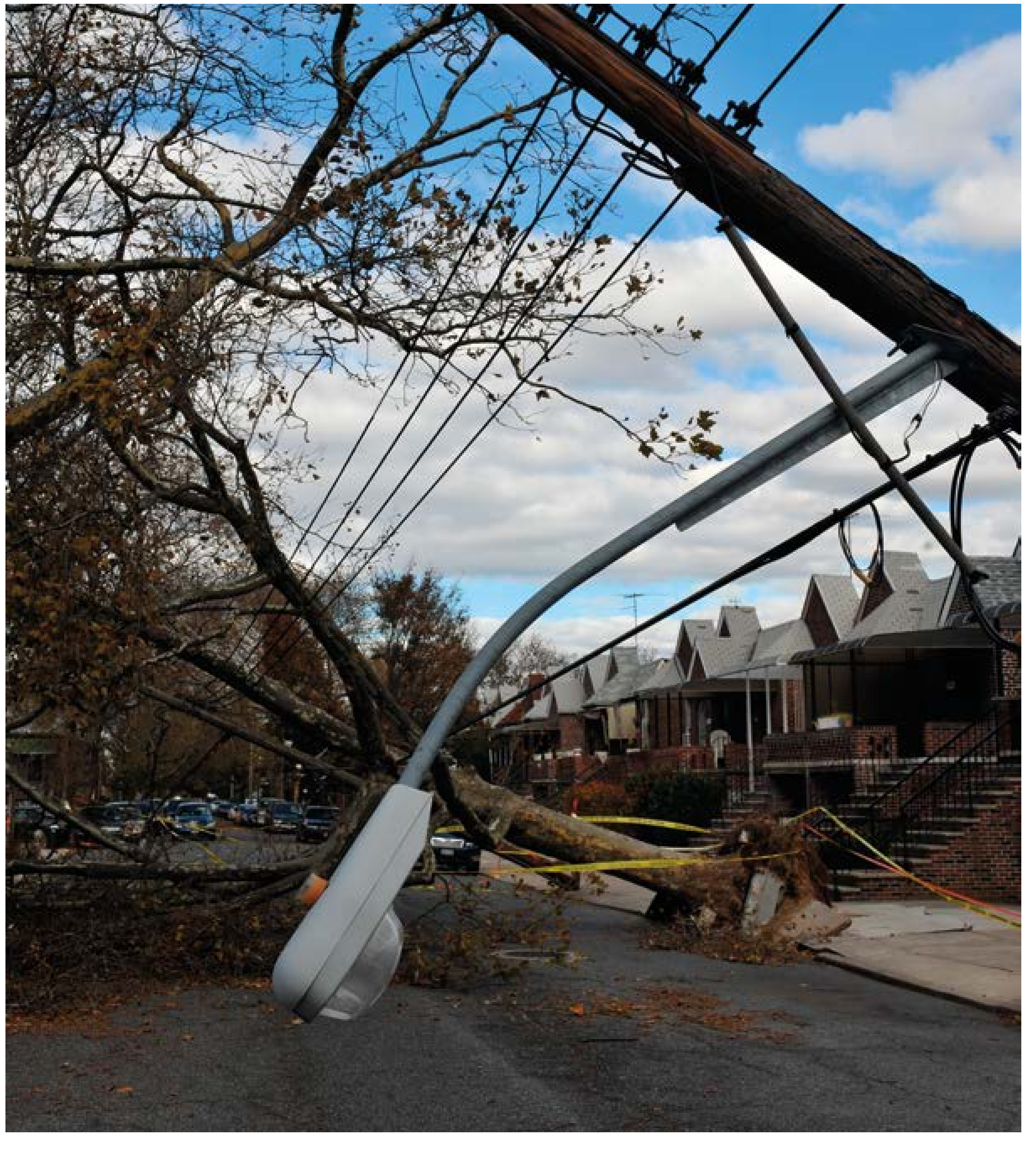
SPECIAL LUMINAIRE FEATURES

The safety of our roads is not only about the light but about the technology used to provide it.

Street and urban luminaires are exposed to the elements and so need to be designed to withstand both the common and exceptional forces of nature in order to be safe and function optimally throughout their life.

The ability of a luminaire to remain safe under demanding natural circumstances is quantified according to two standards: EN 60529 – Degrees of protection provided by enclosures (IP code), and EN 62262 – Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code).



INGRESS PROTECTION

Sometimes referred to as the International Protection Rating, the IP rating given to a luminaire (or other device) expresses its ability to withstand penetration by foreign bodies or liquid. The code consists of two numbers. The first one represents the degree of protection against ingress by anything from a hand to fine particles of dust. The second number represents the degree of protection against ingress by a liquid.

Luminaires for outdoor use in a covered area should have a minimum IP rating of 44, and in the case of possibility of direct contact with water in open areas, a minimum of IP65 in required. As public lighting luminaires undoubtedly get very wet during their service, IP65 is the lowest protection rating permissible.

Luminaires with higher IP rating are more expensive, but the investment is worthwhile in the long term as such luminaires are able to withstand the tests of time and environment, and ultimately last longer, bringing financial and practical rewards later on.

Ingress Protection (IP) rating	
First numeral The degree of protection for people against contact with or approach to live or moving parts inside the luminaire, and protection of the equipment housed in the luminaire against ingress of foreign bodies in accordance with IEC 60598-1:2003	
0	Not protected
1	Protected against solid objects with a diameter of 50 mm or more, and against a large body surface, such as a hand, but not against deliberate access
2	Protected against solid objects with a diameter of 12 mm or more, and against fingers or similar objects not exceeding 80 mm in length
3	Protected against solid objects with a diameter of 2.5 mm or more, and against tools, wires, etc., with a diameter or thickness of 2.5 mm or more
4	Protected against solid objects with a diameter of 1 mm or more, and against wires or other similar solid material with a diameter or thickness of 1 mm or more
5	Protected against dust, which cannot enter in sufficient quantity to interfere with satisfactory operation of the luminaire
6	Closed to dust, which cannot enter at all
Second numeral The degree of protection of the equipment inside the luminaire against harmful ingress by water.	
0	Not protected
1	Protected against dripping water so that vertically falling drops shall have no harmful effect
2	Protected against dripping water so that vertically falling drops shall have no harmful effect when the luminaire is tilted up to 15° from its normal position
3	Protected against spraying water so that water falling as spray shall have no harmful effect when the luminaire is tilted up to 60° from its normal position
4	Protected against splashing water so that water splashing the luminaire from any direction shall have no harmful effect
5	Protected against water jets so that water projected by a nozzle against the luminaire from any direction shall have no harmful effect
6	Protected against heavy seas so that water from heavy seas or projected or powerful water jets shall not enter the luminaire in harmful quantities
7	Protected against the effects of temporary immersion so that water shall not enter the luminaire in harmful quantities even when it is immersed under water under defined conditions of pressure and time
8	Protected against continuous immersion so that the luminaire is suitable for continuous submersion under water due to being either hermetically sealed or because water cannot enter the luminaire in a manner or quantity so as to produce harmful effects

IP rating system.

IMPACT PROTECTION

The IK rating given to a luminaire (or other device) expresses the ability of the cover to withstand and protect the luminaire contents from mechanical impact. A pendulum hammer is used during the testing procedure to carry out a series of impacts according to the EN 60068-2-75 standard. The given rating is applicable to the whole cover unless individual parts are separately rated and labelled.

The rating system works in a similar way to the IP system, using a code with two numbers to indicate impact resistance, with '00' indicating no resistance and '10' representing resistance to an impact energy of 20 Joules. At times, a higher impact resistance in needed, in which case the luminaire cover must withstand an impact energy of 50 Joules. However, there is no given code for this level of resistance. Most luminaires pass the 50 Joule test and are given the IK 10 rating, with those that exceed it given an IK 10 ++ rating.

Impact Protection (IK) rating	
The degree of protection provided by a luminaire enclosure for its electrical equipment against external mechanical impact in accordance with IEC 62262:2002 and IEC 60068-2-75:1997	
00	Not protected
01	Protected against 0.14 joules impact, equivalent to impact from a 0.25 kg mass dropped from 56 mm above the impact surface
02	Protected against 0.2 joules impact, equivalent to impact from a 0.25 kg mass dropped from 80 mm above the impact surface
03	Protected against 0.35 joules impact, equivalent to impact from a 0.25 kg mass dropped from 140 mm above the impact surface
04	Protected against 0.5 joules impact, equivalent to impact from a 0.25 kg mass dropped from 200 mm above the impact surface
05	Protected against 0.7 joules impact, equivalent to impact from a 0.25 kg mass dropped from 280 mm above the impact surface
06	Protected against 1 joules impact, equivalent to impact from a 0.25 kg mass dropped from 400 mm above the impact surface
07	Protected against 2 joules impact, equivalent to impact from a 0.5 kg mass dropped from 400 mm above the impact surface
08	Protected against 5 joules impact, equivalent to impact from a 1.7 kg mass dropped from 300 mm above the impact surface
09	Protected against 10 joules impact, equivalent to impact from a 5 kg mass dropped from 200 mm above the impact surface
10	Protected against 20 joules impact, equivalent to impact from a 5 kg mass dropped from 400 mm above the impact surface

IK rating system.

SELECTING THE RIGHT LIGHT SOURCE

It is important to bear in mind several key technical parameters when choosing the most appropriate light source for each application. In addition, it is wise to evaluate the type of control gear needed and the ability of the light source to be dimmed, both of which greatly affect the overall efficiency of the lighting installation.

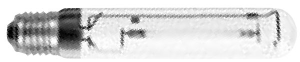
In 2009, the European Commission issued the Commission Regulation (EC) No. 245/2009, amended by the Regulation No. 347/2010 setting EcoDesign requirements for 'Tertiary sector lighting products'. Accordingly, low-performance (standard) high-pressure sodium lamps were removed from the market in 2012, high-pressure mercury lamps and high-pressure sodium plug-in and retrofits will be removed from the market in 2015, and low-performance metal-halide from 2017.

High-pressure mercury vapour (HPM)

One of the earliest light sources to hit our streets after the incandescent bulb, they were a great improvement in terms of lifetime. By today's standards, they are considered ineffective but are still used in old public lighting luminaires. A lot of the consumed energy is emitted as UV radiation, and the visible light is characterised by a blue-green tone and distorted colour perception. Another disadvantage is that the light output decreases over time despite consuming the same amount of energy. The light sources contain mercury and argon. The sale of new HPM lamps and compatible HPS retrofits will be prohibited in the EU from 2015, meaning that lighting systems still using these light sources must be replaced very soon.

Metal-halide (MH)

A popular choice thanks to very good colour rendering properties and pleasant neutral white light, both of which are great improvements over the coloured and almost monochromatic light of sodium and mercury lamps. Many modern metal-halide lamps boast good efficacies, although their lifetimes are relatively poor compared to some other light sources. They have several disadvantages, namely that they emit a large amount of UV radiation, which can be problematic in terms of light pollution and visual and skin irritation in humans, that the light colour shifts over time, and they are known to occasionally fail non-passively, making it necessary to use specialised luminaires that provide protection in the case of the light source exploding. Metal-halide lamps are quite expensive and contain a very large amount of mercury as well as lead and argon. Low-performance metal-halide lamps will be phased out in the EU by 2017. However, there are many high-performance variants on the market.



High-pressure sodium (HPS)

The most widely used light source in street and urban lighting, they were developed to replace high-pressure mercury technology. Highly efficient and with a relatively long lifetime, they have proved to be a practical solution for many years, especially in difficult to access places such as motorways. However, they emit an almost monochromatic light that is perceived as orange or yellow, under which all colours, except orange, appear as shades of grey. For this reason, they are not favoured in terms of safety and security. There are colour corrected versions available, but they are expensive and less efficient. The light sources contain mercury, sodium, neon, argon and lead. Low-performance HPS lamps were banned from sale in the EU in 2012, but high-performance variants are still widely available.

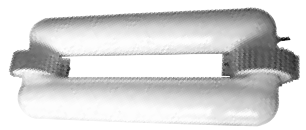
Low-pressure sodium (LPS)

These light sources are used for their very high efficacies and reasonably long lifetimes. However, the light output is monochromatic due to being dominant in two similar spectral wavelengths (589.0 nm and 589.6 nm). This results in no colour rendition, which leads to concerns regarding safety, security and facilitated visual acuity. They contain mercury, sodium, neon, argon and lead. LPS lamps are not covered by the EU directive.

The success of a lighitng system depends on the light source chosen.

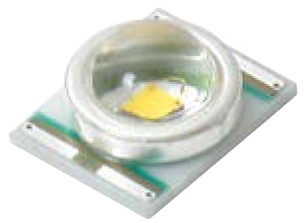
Fluorescent

Typically, the output of these light sources is high in UV radiation and weak in terms of visible light. They are, nevertheless, reasonably efficient and provide good colour rendition. Standard outdoor fluorescent light sources are very large and provide a non-directional light, meaning that that they need to be mounted at a height of no more than 10 m to provide sufficient illumination. They are also highly susceptible to low-voltage failures. Over time, compact versions with better parameters have been developed, although drawbacks of these include their tendency to suffer from heat build-up and relatively frequent failure compared to other light source types. With all fluorescent light sources, the lifetime is greatly reduced by frequent switching, making them unsuitable for use in intelligent streetlighting installations. Another disadvantage is that the light output is affected by low temperatures, with a decrease in luminous flux of around 45 % at 0 °C, reaching about zero and -20 °C. The light sources contain large amounts of mercury.



Induction

Induction light sources are becoming increasingly common thanks to their efficiency and long lifetimes. Still, little is being done in terms of technology development now that LED is taking a strong hold on the market. The light sources are very bulky, and due to their method of creating a current within the lamp, have issues connected with electromagnetic interference (EMI). One of the main disadvantages is that they light output is reduced at lower temperatures, by approximately 20 % at 0 °C, and to nearly zero at -20 °C. The light sources contain lead.



LED

Much of the development happening in the field of light source technology is with regard to LED. Market available LED chips currently have efficacies of up to 160 lm/W with laboratory trial efficacies reaching in the region of 300 lm/W. This, combined with long lifetimes of up to 100,000 hours in streetlighting application, make LED an efficient and low-maintenance option. LEDs provide a pleasant white light with good colour rendering properties and are not negatively affected by switching or dimming. Other advantages include flexibility due to their controllability and that they allow for the use of high-performance optics that ensure better lighting uniformity, more precisely tailored light distributions and little light pollution, all of which mean that the illumination is more effective and energy consumption reduced. LEDs for streetlighting must be used in LED-specific luminaires, and currently, the high price of these technologies are an obstacle to significant uptake.

Light source	Lifetime [hours]	Power [W]	CCT [K]	CRI [Ra]	Efficacy [lm/W]	Control gear	Ignition time / restrike delay [mins]	Control	Advantages	Disadvantages
Mercury vapour	12,000–24,000	50–1000	3200–4200	20–60	40–60	Electronic / magnetic	Up to 15 / restrike delay	Not possible	None	Low efficacy UV radiation
Metal-halide	6000–20,000	20–2000	4200–6000	65–95	70–110	Electronic / magnetic	Up to 15 / restrike delay	Step dimmable 60–100 %	High CRI	UV radiation Risk of exploding at end of lifetime
High-pressure sodium	12,000–32,000	50–2000	2000–2200	≥25	60–150	Electronic / magnetic	Up to 15 / restrike delay	Step dimmable 60–100 %	High efficacy Long life	Low CRI Orange or yellow light
Low-pressure sodium	12,000–18,000	10–180	1800	0	80–200	Electronic / magnetic	Up to 15 / restrike delay	Not possible	High efficacy	Monochromatic orange light
Fluorescent	10,000–20,000	4–80	2700–8000	60–99	60–100	Electronic / magnetic	Up to 5 / no restrike delay	Dimmable 0–100 %	High CRI Low price	UV radiation Output reduced by low temperatures Diffused non-directional light
Induction	60,000–100,000	cca 15–600	2700–6500	70–90	70–90	Electronic	Up to 5 / no restrike delay	Dimmable 30–100 %	Long life High CRI	UV radiation Output reduced by low temperatures Diffused non-directional light Large size
LED	50,000–100,000	full range	2700–8000	85–90	70–165	Electronic	Immediate	Dimmable 0–100 %	High efficacy Long life High CRI	Relatively higher initial cost

Quick light source comparison.

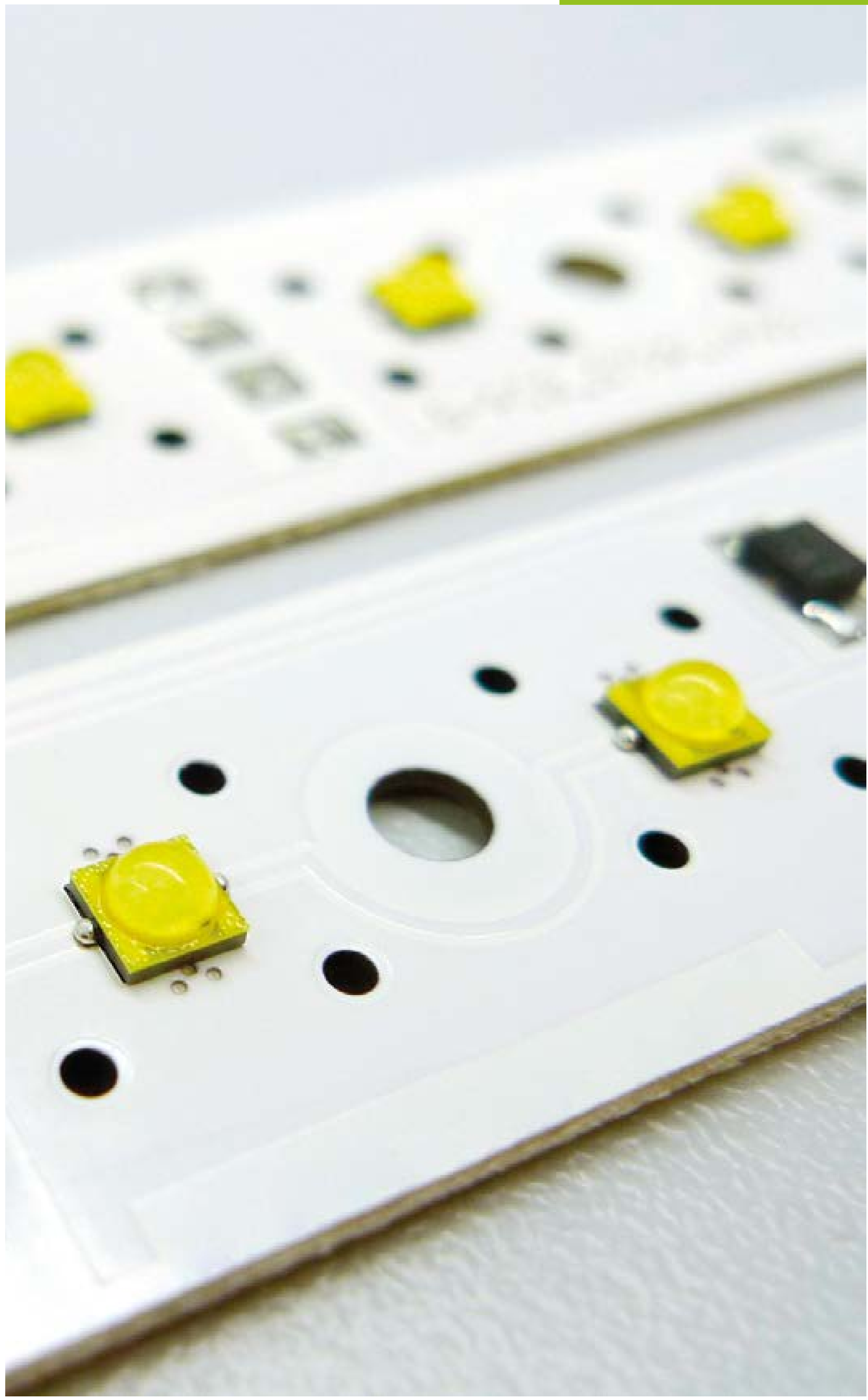
LED FOR STREET & URBAN LIGHTING

LEDs now have lifetimes of up to100,000 hours, which equals 25 years of operation at 11 hours per day, 365 days per year.

When in 1962, the American professor Nick Holonyak created a prototype of the first 'Light Emitting Diode' (LED), it went almost unnoticed. The only one who anticipated its revolutionising future in the pages of Reader's Digest magazine was the inventor himself. It was almost 40 years before the industry began to realise the exceptional properties of LEDs and start learning how to harness them. Now LED is the most dynamic field of advancement in the entire lighting industry.

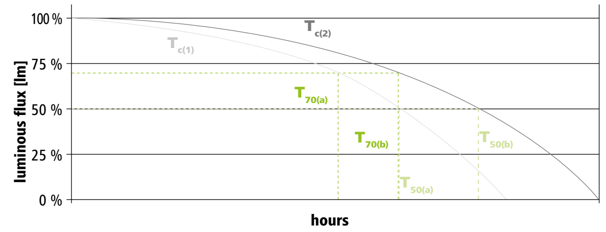
So, what is it exactly that makes LEDs so special, and how is it that their properties and parameters surpass those of conventional light sources? Why do urban planners and lighting designers increasingly concentrate on the use of LEDs in the design of their lighting systems? Like any answer to any question, there is a short version and a long version. The short version is that LEDs are highly effective, have long lifetimes, excellent light parameters and are cost-effective and environmentally friendly. However, to truly understand we must look at each property in detail starting with what LEDs actually are.

LEDs are semiconductor diodes that emit light by a process called electroluminescence. Each diode consists of two types of semiconductor, an N-type with surplus electrons and a P-type with a deficiency of electrons (called holes). When a current is passed through the semi-conductors, the surplus electrons from N and the holes from P recombine to produce photons, commonly known as electromagnetic radiation, some of which we perceive as light. Most LEDs produce photons in the blue part of the visible spectrum, which need to be transformed into 'white' light using modifying phosphor layers. The light emitting part of the LED, the die, is, in fact, no bigger than the dot made by a pencil. It is enclosed within a 'package', most of which is a lens used to direct the light and at the same time protect the tiny die.



How effective are LEDs

The beam angle of an LED ranges between 15° and 180°, which allows the light to be harnessed and directed very precisely, which minimises the amount lost within the optics of the luminaire and as light pollution. This is something very different to conventional light sources that usually emit light in a very wide beam angle. This means less light needs to be emitted to achieve the same level of illumination when using LEDs, which reduces energy consumption. Additional aspects of the energy consumption argument include the fact that LEDs are more effective, with up to 55 % of consumed energy being converted into visible light as opposed to the 5 % of an incandescent bulb and 35 % of a fluorescent lamp. Another interesting value is the luminous efficacy of a light source, which is the calculation of how many lumens you get from one watt, or lm/W. The first white LEDs in the mid-90's had an efficacy of 0.1 lm/W, however there are now commercially available LEDs with cool CCTs that offer an efficacy of more than 165 lm/W. In laboratory trials, efficacies of more than 300 lm/W have been achieved, illustrating great potential. To put this in context, LEDs with an efficacy of 165 lm/W are 10 % more effective than high-pressure sodium with 150 lm/W, 50 % more effective than metal-halide with 110 lm/W, 65 % more effective than fluorescent with 100 lm/W and an amazing 1000 % more effective than the incandescent blub with 15 lm/W.



LEDs do not fail but the intensity of the light they produce diminishes over time. The lifespan (L) of an LED thus needs to be defined for different applications. The lifespan of an LED depends to a large extent on ambient and operating temperatures. Where an LED is operated at a high temperature (Tc1) or with poor thermal management, its life is shortened.

Lifetimes

The types of LED used in street and urban settings have a lifetime of up to 100,000 hours and very low failure rates. In practice, this means that a light source in operation 11 hours per day, 7 days per week will last for 25 years, something not attainable with conventional light sources. Reductions in performance are inevitable, but happen towards the end of the LED's life and can be compensated for during the design of the lighting system. However, it is important that LEDs be effectively cooled as their lifetime is reduced, and they operate less effectively under high temperatures. That is why it is vital to use quality luminaires where this factor is fully accounted for.

Cost

It is true that, at the moment, LEDs are more expensive, but that is merely one factor in the equation. In order to fully appreciate the cost-effectiveness of LEDs, you need to think long term and not only about the initial investment. LEDs, as previously mentioned, use a lot less energy than conventional light sources. It is estimated that if all light sources were replaced with LEDs it would provide 30 % savings in energy, and if we think that artificial lighting accounts for 20 % of the overall consumption of electrical energy, that is no small difference. Even higher savings can be provided when LEDs are used to replace older and less efficient light source types. Furthermore, as the lifetime of LEDs is longer, savings can be made on the replacement of light sources over time and all costs associated with maintenance. LEDs are also infinitely controllable by Lighting Management Systems, further expanding the savings potential available. And lastly, the disposal of LEDs at the end of their life is much easier than for other light sources, further reducing their overall cost.

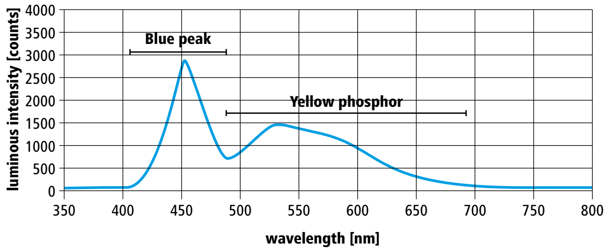
Environmental impact

LEDs consume less energy and contain almost not hazardous content. Reduced energy consumption, of course, means fewer resources are used to produce the energy, and less waste is created as a by-product of that process. Moreover, the hazardous material content of LEDs is very low compared to conventional light sources, most of which contain significant quantities of toxic heavy metals in a gaseous state, making them dangerous when damaged and harmful when disposed of. LEDs do contain a very small amount, but in a solid state which means that even if damaged they pose no threat to us, and those small amounts of material are simple to separate and dispose of once the time comes.

Spectral distribution

Light colour is defined using the CIE 1931 chromaticity system. The Planck curve represents the ideal combination of all primary colours for human visual perception, against which can be mapped the whole range of Correlated Colour Temperatures (CCT) from very warm (2500 K) to very cold (10,000 K). Each type of light source has its own specific chromaticity coordinates, most of which lay somewhere along the Planck curve, and its own spectral distribution, which is the amount of photons emitted at each wavelength or the ratio of colours within the light. The spectral distribution of every light source can be mapped, from which we can learn much about the nature of the light emitted.

Another interesting feature of the different spectral distributions is that LEDs generally emit more photons at all visible wavelengths. This is perceived by the human eye as good colour rendition. However, not all CRI values are equal. Metal-halide light sources display all colours in a reasonably balanced way and, therefore, have good colour rendition. LED on the other hand displays all colours, especially blue, with much higher definition, which means that CRI ≥ 90 in LED has more depth than CRI ≥ 90 in metal-halide. The colours are truthful but have a more lifelike and saturated colour under LED light sources, more like under natural daylight.



During his colour matching experiments in the early 1700s, Sir Isaac Newton discovered that white light can only be produced by combining blue and yellow light.

Colours straight from the semiconductor

LEDs do not require colour filters. The colour tone of the light is determined by the semiconductor material used and its dominant wavelength. Secondary colours are also possible. The major semiconductors are:

Semiconductor material	Abbreviation	Colour(s)
Indium gallium nitride	InGaN	green, blue, (white)
Aluminium indium gallium phosphide	AlInGaP	red, orange, yellow
Aluminium gallium arsenide	AlGaAs	red
Gallium arsenide phosphide	GaAsP	red, orange, yellow
Silicon carbide	SiC	blue
Silicon	Si	blue

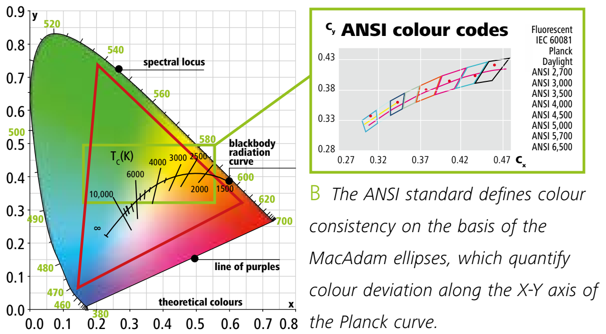
The influence of used semi-conductor materials on emitted light colour.

Colour consistency

During the production of LEDs, deviations occur between individual batches with regard to various lighting parameters such as light colour. Within one batch, the parameters are almost identical, but between two batches the differences can be very apparent. To ensure consistent light quality, it is necessary to sort every batch according to their individual lighting parameters, a process called 'binning'. The main criteria considered during binning are the luminous flux (lm), CCT (K) and forward voltage (V).

Colour consistency needs to be thought about in two ways. Firstly, it is important to choose a luminaire manufacturer that uses high quality LEDs, in this way you are assured that when installing a new lighting system, all the luminaires will emit a perceptibly consistent light colour. Secondly, you need to think about what happens next, as all light sources emit light of a different colour after time, and LEDs are no exception. Your new installation can look perfect when new, but after five years the light colour of the luminaires can vary greatly (A). Nowadays LEDs are classified according to the ANSI standard (B) that defines colour consistency on the basis of the MacAdam ellipses, which quantify colour deviation along the X-Y axis of the Planck curve between warm and cold, or above and below the Planck curve to green or pink. ANSI recommends that LEDs be within three threshold values of each other to be acceptable in use together. To put that in context, a difference of three steps is barely noticeable.

What this means in practice is that, if all installed light sources begin with a CCT of 3000 K, they cannot change colour by more than three steps. This refers not only to the difference of one light source, but to the difference between all light sources in an installation. For example, one could move more towards a cooler colour temperature and another towards a warmer colour temperature, but the difference between them should be no more than three steps or else the deviation will be clearly apparent. Very high quality LEDs have a difference of only two steps over their lifetime, however, a difference of three or four steps is standard. Some LED manufacturers have developed complex processes by which they can sort LEDs also according to the direction of deviation, keeping any visual discrepancy to a minimum.



B *The ANSI standard defines colour consistency on the basis of the MacAdam ellipses, which quantify colour deviation along the X-Y axis of the Planck curve.*

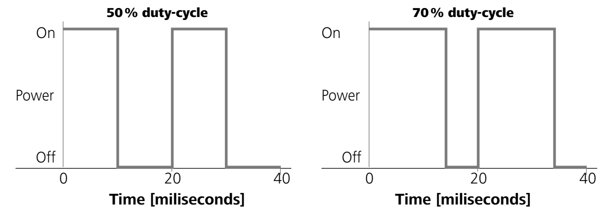
To achieve consistent and reliable luminous output, it is important to select quality luminaires.

Thermal management

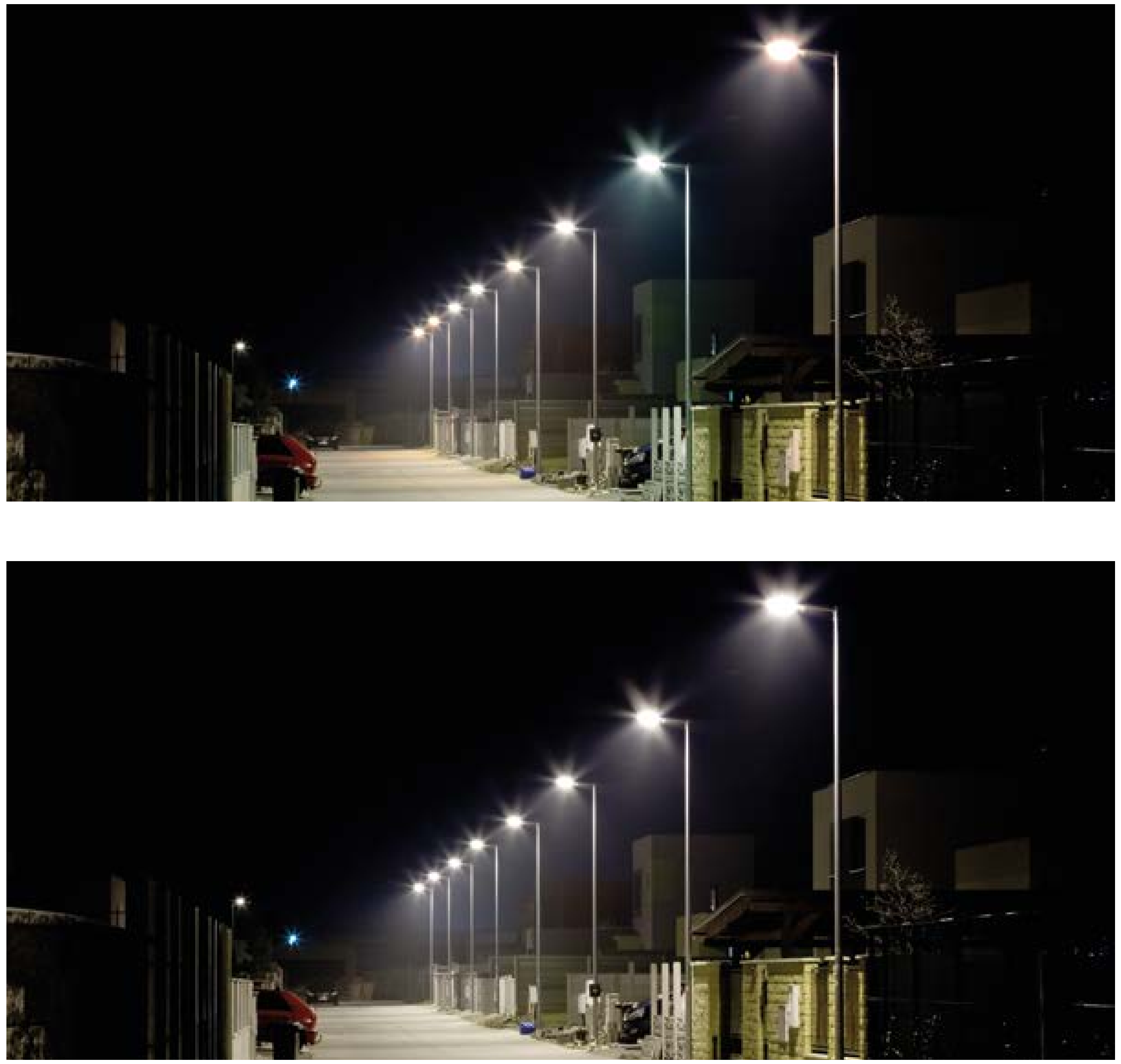
LEDs are greatly affected by temperature, just like any other light source. However, LEDs function in a different way, with heat being more detrimental than cold, and can reduce the lifetime and increase the risk of damage. For that reason, it is vital that LED luminaires be designed with adequate thermal management to prevent overheating of the LEDs.

PWM control

Pulse Width Modulation (PWM) is the most effective method by which to regulate the luminous intensity of an LED light source. It functions by periodically switching the constant current supplied to the LED on and off at a rate that is imperceptible to the human eye. This can change the apparent brightness of the emitted light while maintaining visual and colour temperature consistency.



Unlike conventional light sources, LEDs emit their full luminous flux immediately, which is a great advantage in terms of safety and comfort. Furthermore, frequent switching does not negatively affect the lifetime of LEDs. Both of these features make LEDs perfect for PWM regulation.



A *In the top image, the light sources emit perceptibly different light colours. Although this phenomenon does not noticeably affect visual acuity, it is aesthetically displeasing.*

GLOSSARY

Carriageway
The area of a road designated for motor vehicle traffic, often consisting of two or more lanes in each direction.

Colour Rendering Index (CRI)
The ability of a light source to render the colours of illuminated objects truthfully compared to an ideal control light source such as sunlight. This is assessed using a set of 8 test colours. The unit is Ra, although commonly referred to as CRI.

Contrast
The difference between the relative luminance of an object compared to its background.

Correlated Colour Temperature (CCT)
The perceived colour of white light, ranging from warm red, orange and yellow tones to cool blue tones. The unit is kelvins [K].

Glare
A condition caused by areas within the field of vision that are brighter than the object or area of focus. The excessive contrast between light and dark reduces visual acuity and causes discomfort and fatigue.

Discomfort glare
Glare that causes visual discomfort without obviously impairing or restricting visual acuity.

Disability glare
Glare that makes it difficult to recognise objects, making vision visually, physically and psychologically tiring.

Blinding glare
Glare that is so intense that visual acuity is reduced to a minimum or completely. The effects can persist for some time even once the source of glare is removed.

Threshold increment (T_I)
Quantification of the loss of visual acuity resulting from disability glare caused by luminaires.

IK rating
A rating system used to express the ability of a cover to protect equipment within the housing against mechanical impact. The numerical code used after the letters 'IK' represent the level of protection ranging from 00 to 10, and 10++.

Illuminance (E)
The quantity of light falling on a surface. The unit is lux [lx].

Average illuminance [E_{av}]
The average of the quantity of luminous flux falling on road surface over a given area.

Minimum illuminance [E_{min}]
The lowest quantity of luminous flux falling on a road surface over a given area.

Horizontal illuminance [E_h]
The quantity of luminous flux falling on a horizontal plane or surface.

Vertical illuminance [E_v]
The quantity of luminous flux falling on a vertical plane or surface.

Minimum vertical illuminance ($E_{v, min}$]
The lowest vertical illuminance at a defined height above the road surface.

Semi-cylindrical illuminance [E_{sc}]
The quantity of luminous flux falling on the curved surface of an upright semi-cylinder. It is the type of illumination that aids recognition of objects and faces.

Minimum semi-cylindrical illuminance [$E_{sc, min}$]
The lowest semi-cylindrical illuminance at a height of 1.5 m above the road surface.

Hemispherical illuminance [E_{hs}]
The quantity of luminous flux falling on the curved surface of a hemisphere placed on an assessed surface. It is utilised in a similar way to horizontal illuminance.

Average hemispherical illuminance [$E_{hs, av}$]
The average hemispherical illuminance of a given road surface.

Ingress (International) Protection [IP] rating
A rating system used to express the ability of a device to withstand penetration by foreign bodies and liquid. The double numerical code used after the letters 'IP' denote i) protection against ingress by solid objects ranging between 0 and 6, and ii) against liquids ranging between 0 and 8.

Lane
The area of a road designated for a single line of traffic flow. On smaller roads, there is one lane in each direction of the traffic flow. Larger roads often consist of multiple lanes in each direction, in which case the designated area for traffic flow across all lanes in one direction is referred to as the carriageway.

Lifetime
The amount of time a light source is expected to perform to a defined level before it fails to meet requirements or stops functioning. It is quantified in hours [h].

Light Intensity Distribution Curve (LIDC)
The shape of the light distributed from a light source or luminaire.

Lighting uniformity [U]
How evenly light is distributed across a surface, with high uniformity minimising the need for the eye to adapt to changes in luminous intensity.

Overall uniformity (of road surface luminance, illuminance falling on a road surface or hemispherical illuminance) [U_0]
The ratio of the lowest to average luminance value of an assessed surface.

Longitudinal uniformity (of road surface luminance of a driving lane, or of a multi-lane carriageway) [U_l]
The ratio of the lowest to the highest road surface luminance found along the central line of a driving lane or the lowest longitudinal uniformity of the driving lanes of a multi-lane carriageway.

Light Output Ratio (LOR)
How effectively a luminaire redistributes the light emitted by the used light source(s). It expresses how much light is lost within the optical system and, therefore, how effective the luminaire is. An LOR is expressed as a percentage [%].

Light pollution
Artificial light emitted by luminaires and other devices in a way that is neither needed nor desired, such as onto neighbouring properties, through windows and into the night sky.

Light source efficacy [η]
How effectively a light source converts the consumed electrical energy into useful light. The unit is lumen per watt [lm/W].

Luminance [L]
The light we perceive as it is reflected into our eye in relation to a specific surface. The unit is candela per square metre [cd/m^2].

Average road surface luminance (of a carriageway of a road) [L_{av}]
The average luminance of the road surface over the carriageway.

Luminous flux [Φ]
The total quantity of useful light emitted by a light source. The unit is lumen [lm].

Luminous intensity (I)
What we would commonly refer to as brightness, it is the level of luminance perceived from a given surface in a particular direction. The unit is candela [cd].

Maintenance factor [MF]
A value used to determine the degree of over-dimensioning required to ensure a lighting installation fulfils requirements for its defined lifetime.

Maintained luminance
The maintained level of average luminance, average or minimum illuminance, average hemispherical illuminance, minimum semi-cylindrical illuminance or minimum vertical illuminance of a road surface, calculated by reducing the designed level by the maintenance factor.

Power
The quantity of electrical energy required to power a device. The unit is watts [W].

Reflectance
The ratio of the luminous flux falling on a surface to that reflected by the surface in relation to its construction material and luminance.

S/P ratio
The ratio of scotopic to photopic vision used to determine the visual effectiveness of the light emitted by a given light source according to the sensitivity of the human eye to its spectral composition.

Scotopic vision
Vision in poorly-lit conditions facilitated predominantly by the rods in the eye and their sensitivity to the blue and green parts of the spectrum.

Photopic vision
Vision in well-lit conditions facilitated predominantly by the cones in the eye and their sensitivity to the yellow and red parts of the spectrum.

Mesopic vision
Between scotopic and photopic vision, it is facilitated by both the rods and cones in the eye.

Surround ratio of illumination (of a carriageway) [SR]
The average illuminance of areas bordering the illuminated carriageway in relation to the average illuminance of the carriageway or part of the carriageway.

System efficacy [η]
How effectively a luminaire, including its light source and supporting equipment, convert the consumed electrical energy into useful light. The unit is lumen per watt [lm/W].