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Roads, paths and squares

01

Editorial

Dear readers,

Modern lighting is a future-proof investment for any town or city. Good lighting ensures safety for passers-by, reduces the risk of traffic accidents and, as an element of design, plays a significant role in creating an attractive urban environment.

In recent years, demand for energy-efficient lighting solutions has increased sharply at municipal level. A new statutory environment and the switch to LED lighting technology present major challenges for municipal authorities and reveal the need for action in this area. In addition, current societal developments such as the increasing concentration of population in urban areas show the need to adapt urban environments and their transport networks to these circumstances. In order to guarantee high quality of life in the long term, targeted investment in sustainable infrastructure with intelligent lighting solutions is required. Recent assessments of the street lighting situation in Germany show that the efficiency of lighting installations in many localities is poor. Lighting for public roads, paths and squares alone still currently accounts for 30 to 50 percent of municipal power consumption. That causes high costs and negative climate impacts. Energy-efficient lighting solutions are major opportunities to cut costs and help mitigate climate change.

A front-line role in energy-efficient outdoor lighting is currently played by LED technology. Its massive potential permits high luminous efficacy at very low levels of energy consumption. Switching from conventional light sources to innovative LED systems with intelligent control, for instance, can reduce energy input and carbon output by 80 percent or more.This booklet presents model solutions for optimising public lighting in line with the latest technological developments, current standards and legal requirements. It is intended as an orientation aid for local authority decision-makers and planners involved in modernisation projects. Valuable background information is also provided by clear tables and illustrations, e.g. on the basics of lighting design.

Useful checklists and tools as well as an overview of current incentive funding options are included to facilitate practical implementation. After all, future-proof lighting concepts will benefit towns and cities in many ways: they will reduce environmental impacts, enhance the quality of urban life and lend impetus to responsible use of limited energy resources. Use of more efficient technology is vital if we are to achieve the ambitious savings targeted in Germany and Europe through to 2020 and 2030. Without a switch to new lighting technologies, especially to LED, it will be very difficult to reach the goals set.

Parliamentary State Secretary Andreas Scheuer

[Cover] The primary task of street lighting is to ensure good visibility and safety on the roads. It is particularly important in conflict areas, where different types of road users are present at the same time.

[01] Lighting enhances the visual impact of building facades at night and lends atmosphere to the urban environment.

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Municipal lighting tasks

Thanks to modern LED technology, lighting for public spaces is in transition. Lighting has never before been so innovative, flexible and efficient – which opens up totally new possibilities and perspectives for technical and decorative municipal lighting.

[02, 03] Modern lighting can make for attractive skylines and streets without putting pressure on budgets and the environment. LED technology has made huge advances in recent years and done a lot to reduce energy bills and carbon emissions.

[04] The primary task of municipal lighting is to promote safety wherever there is traffic. Applications range from motorways and expressways to paths through parks.

Road safety, energy efficiency, life cycle costs, the need for refurbishment, procurement of spare parts, resident and user satisfaction – modern municipal lighting can throw up lots of questions but also present myriad opportunities. That said, the requirements that good lighting needs to meet are the same as ever.

Greater road safety

The most important task that road lighting needs to address seems easy: to create conditions enabling all road users to see well enough. But accomplishing that task involves negotiating a number of hurdles. Where a lighting plan is drawn up for a public space, the minimum normative requirements set out in DIN EN 13201 need to be observed. Those requirements take account of all major factors such as traffic density, carriageway width, mounting height of light sources, column spacing and road type. As a matter of principle, all roadways should be illuminated so that every road user is able to adapt to changing traffic situations. Sudden holdups need to be clearly perceptible from a distance so that prompt and correct responsive action can be taken. Street lighting plays an active role here in lowering accident risk, both on roads and in other traffic areas.

A greater sense of security for passers-by

Good – and above all adequately bright – lighting for paths and squares helps significantly reduce assaults on passers-by and property. High illuminance has a deterrent and preventive effect. It helps make the features or intentions of an approaching figure easier to recognise and thus permits an appropriate response. So people have a greater sense of personal safety and shady characters are deterred from the outset.

More attractive urban environment

Lighting plays a significant role in shaping the face of a municipality. During the day, the physical presence of the luminaires –either as discreetly embedded elements or outright eye-catchers – adds attractive visual details to the urban landscape. At night, the light that is emitted determines whether people can see well and feel comfortable in their surroundings. Although functionality is a prime requirement here, lighting is also instrumental in defining atmosphere and ambience. Charmingly illuminated towns and cities attract visitors and customers for the local business community.

Lower costs plus lower carbon emissions

In recent years, LED technology has also gained acceptance in the area of street lighting. LEDs have massive performance potential and their light can be very precisely directed with minimum scattering loss. They can also be dimmed to deliver no more light – and consume no more power – than is actually necessary. For a given lighting task, an LED luminaire requires up to 80 percent less energy and generates as much as 80 percent less CO_2 than a conventional street light. Operating costs and negative environmental impacts can thus be reduced. However, that potential can only be fully exploited if quality luminaires are used. All components – from housing to control system, to lighting technology – need to be properly coordinated.

The basics of lighting

Correct lighting makes for safety and comfort in towns and cities. Anyone who has anything to do with lighting or lighting design should be familiar with the basics of lighting.

The four basic lighting quantities

1) Luminous flux is measured in lumen (lm) and defines the visible light radiating from a light source in all directions.

2) Luminous intensity, measured in candela (cd), is the amount of luminous flux radiating in a particular direction. Luminous emittance is a distinguishing feature of many different luminaires and reflector lamps. It defines how their light is distributed on the road.

3) Luminance is the brightness of a luminous or illuminated surface as perceived by the human eye. Measured in candela per square metre (cd/m²), it expresses the intensity of the light emitted or reflected over a defined area of the surface.

4) Illuminance is the luminous flux falling on a given surface from a lamp. The unit of measurement is lux (lx), one lux being the illuminance produced by one lumen of luminous flux spread evenly over an area of one square metre. Example: the flame of an ordinary candle produces approximately one lux from a distance of one metre.

Level of brightness needs to be appropriate for visual tasks

An adequate level of brightness (lighting level) is a fundamental requirement for being able to see well outdoors. It needs to take account of the visual tasks performed by road users and to support the various activities required to reduce the risk of accidents. Illuminance, the reflective properties of the illuminated surface and luminance are crucial for this. Illuminance (lx) here defines the luminous flux falling on a particular area from a light source.

Luminance

Luminance (cd/m2) expresses the subjective impression of brightness. It is the brightness of an illuminated or luminous surface as perceived by the human eye. Crucial here is the intensity of light in relation to the size of the surface. Luminance and the way it is distributed over the task area or the area around it influence how quickly, reliably and easily objects can be identified and responsive actiontaken.

Reflectance

Reflectance indicates how much incident luminous flux is reflected by a surface. The brighter the surface is, the higher the reflectance and the greater the illumination of the surroundings. Reflectance can reach 85 percent in the case of light-coloured facades and averages 27 percent in the case of a standard concrete road surface.

Adaptation time of the eye

The time it takes for our eyes to adapt to bright and dark lighting situations has major implications for visual performance. Visual impairment occurs when our eyes have too little time to adjust to differences in brightness, especially marked differences. Light adaptation, i.e. adapting from dark to light, is a faster process than dark adaptation. When our eyes have to adapt from light to dark, they require significantly more time to do so (in some situations several minutes). That is why adaptation zones are provided – e.g. at tunnel entrances and exits – to make for a safe transition from light to dark and vice versa.

Glare and veiling luminance

Visual performance is severely impaired and visual comfort sharply reduced by glare. Glare can be direct (caused by luminaires, the sun or very bright daylight) or reflected (due to light reflected from shiny surfaces). Luminaire glare can be limited by appropriate optics.

Veiling luminance occurs where light from a source close to the object viewed interferes with vision by generating a powerful light stimulus and casting scattered light onto the retina. This spreads over the retina like a veil and reduces contrast perception. Driving at night with oncoming traffic is a classic example of a situation where veiling luminance can occur. The brighter the light source and the closer it is, the greater the visual impairment. In older people, the effects of light scatter are more pronounced than in younger people because the lens of the human eye becomes more opaque with age.

Assessment of glare on the basis of glare rating values (glare rating method)

Glare is caused by patches of brightness within the visual field and significantly interferes with perception. In many people, glare also gives rise to discomfort, insecurity and rapid fatigue, e.g. when driving a car at night. In this case, experts speak of discomfort or psychological glare. To avoid errors, fatigue and accidents, it is important to limit glare. The degree of direct glare from luminaires or other light sources impairing visual performance is defined for outdoor workplaces and sports facilities by glare ratings GR.

Assessment of glare on the basis of percentage threshold increments (TI method)

In road lighting, glare rating is based on an assumed viewing direction for the motorist. The parameter used for measuring physiological (disability) glare is the percentage threshold increment TI and the control requirements are set out in DIN EN 13201.

Light colour

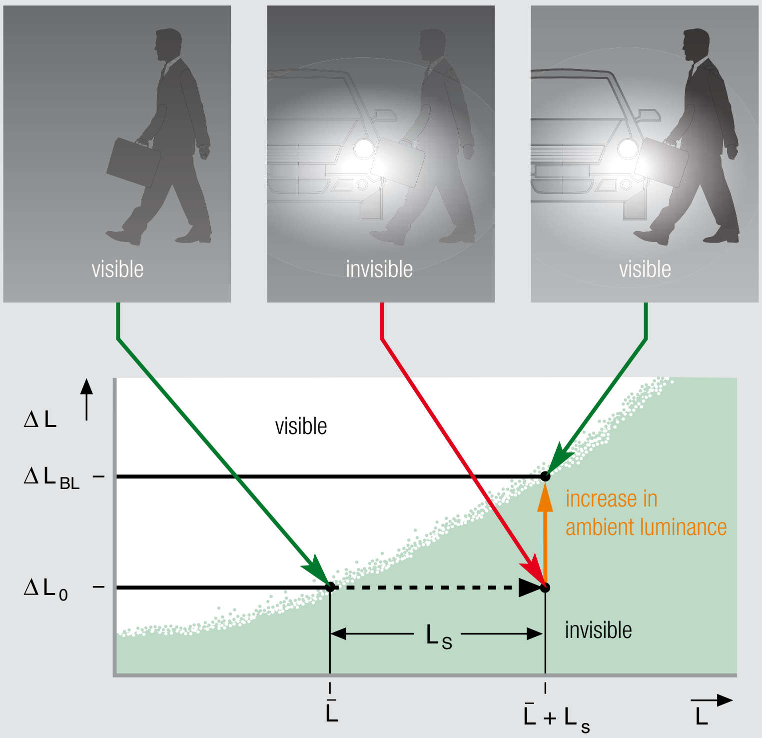
Light colour is the intrinsic colour of the light radiated by an artificial light source. The lower a lamp's Kelvin (K) rating, the 'warmer' its light appears. Low colour temperatures produce a warm yellowish or reddish white light, as in the case of sodium vapour lamps, halogen lamps and warm white fluorescent lamps. Highcolour temperatures produce cold bluish white light colours similar to daylight (at around 6,500 K) on an overcast day. Examples include neutral white and daylight white fluorescent lamps as well as metal halide lamps. As a general rule, a distinction is made between three light colours: warm white below 3,300 K, neutral white from 3,300 to 5,300 K and daylight white above 5,300 K.

Colour rendering

The colour rendering index R_a indicates how well colours illuminated by artificial light can be accurately perceived. The colour rendering of conventional lamps ranges from R_a 20 toR_a 100 and depends crucially on the quality of the light source. Where the colour rendering index R_a is 100, colour rendering is optimal and all colours appear natural. Metal halide lamps reach values between R_a 60 and R_a 95. LEDs can also have very good colour rendering indices between R_a70 and R_a95. High-pressure sodium vapour lamps, by comparison, have a significantly lower index, typically R_a25. The main benefit of a high colour rendering index is visual comfort, so it is particularly appropriate for pedestrian precincts and for illuminating facades and buildings.

More information on this subject is found in licht.wissen 01 "Lighting with Artificial Light".

Increase in ambient luminance



Under glare-free road lighting at night, the eye adapts to the average luminance of the road (L). In this case, persons or objects on the road are recognisable if their luminance contrast in relation to their surroundings is ΔL_0. Where dazzling light sources occur in the visual field – oncoming vehicles, for instance – they produce scattered light which spreads like a 'veil' over the retina.

The eye tries to compensate for the glare and "veiling luminance" (L_S) and adapts to a higher level L + L_S. Objects on the road can then no longer be made out. Raising the ambient luminance from ΔL_0 to ΔL_{BL} renders them visible again.

05

Lighting design and standards

Correct lighting is a major factor for safety on roads and paths. Lighting, normative and design requirements are very high and call for designers and professionals with extensive expertise. Below is a brief overview of the key parameters.

The requirements that need to be met by lighting are determined by the hazard potential of the stretch of road in question. As traffic increases, so does the risk of collisions. What is more, if the space on and alongside the road is used by different road users, such as motorists, cyclists and pedestrians, the hazard rating is significantly higher because of the marked differences in velocity, size and recognisability. Another parameter is the clarity of the road, which depends on the course and width of the road and the speed limit that applies on it. All of these factors need to be considered when assessing the lighting level required. Basically: the higher the risk of accidents, the more light the street lighting needs to provide.

Lighting level

Lighting level is one of the most important criteria for municipal lighting. Here, planning is based on different lighting variables, depending on speed limits. Where they are higher than 30km/h, as in the case of trunk roads, motorways and even tunnels, luminance (candela per m^2) is the yardstick used. Where speed limits are 30km/h or less, e.g. in traffic-calmed areas or car parks, illuminance (lux) is the required design criterion.

Roadway luminance

Luminance (L) on the road is essentially determined by two factors: the illuminance and reflective properties of the illuminated surfaces. Illuminance depends on the number and arrangement of light sources, the way their light is distributed and the luminous flux of the lamps used.

Reflectance

The darker and matter a surface is, e.g. the surface of the roadway or a building facade, the lower its reflectance and the more light is needed to illuminate it. Help is available for designers in CIE publications 94:1993 and 136:2000, which contain recommended minimum illuminance values for taking account of the reflectance of illuminated surfaces.

Duty to ensure safe roads

To cut costs, some local authorities switch off every second street light during the quiet night hours between 11 p.m. and 5 a.m. The resulting partial lighting creates dangerous dark ‘camouflage’ patches, which significantly increase the risk of accidents. This dubious money-saving practice breaches a local authority’s duty to ensure safe roads. If accidents occur, court cases and compensation claims are pre-programmed. In a ruling delivered on 3 May 2013, Limburg Regional Court ordered the municipal authority of Herborn to pay compensation to a passer-by who suffered injury at night where street lighting had been deactivated.

According to DIN EN 13201, the lane ahead of the motorist needs to meet particular requirements in terms of uniform distribution of luminance and illuminance (see also Figs. 06 and 07 on the facing page). Where individual luminaires are deactivated, accident risk increases. This is largely because motorists are confident that they can see and fail to recognise other road users in the dark zones until it is too late. So, for motorists and pedestrians alike, camouflage zones are a safety hazard. To eliminate such hazards from the outset and still enjoy energy economies, new technologies are the answer. Modern controllable LED luminaires, for example, enable the lighting level of all the luminaires on a stretch of road to be electronically dimmed without creating dark patches. More information on this is found in the chapter on lighting management on pages 18-19.

Approach for determining road lighting quality features

DIN 13201 classifies local conditions and defines lighting quality features in a series of steps. The basic approach for defining lighting performance requirements is as follows:

1. **Classification** of the road according to the lighting situations A1 to E2 defined in DIN 13201-1 (see Fig. 08 on the facing page).
2. **Selection of the lighting class** on the basis of the standard and supplementary tables (1.4-13) in DIN 13201-1 and DIN EN 13201-2. The planning aid on page 13 offers help here.
3. **Establishment of the lighting design** requirements on the basis of tables 1.4-16 to 1.4-18.

[06, 07] Switching off every second luminaire creates ‚camouflage zones‘, which present a major hazard on roads. Dark patches can be avoided by uniformly dimming all luminaires.

[08] Applying basic parameters enables the type of road to be assigned to one of the lighting situations set out in DIN EN 13201.

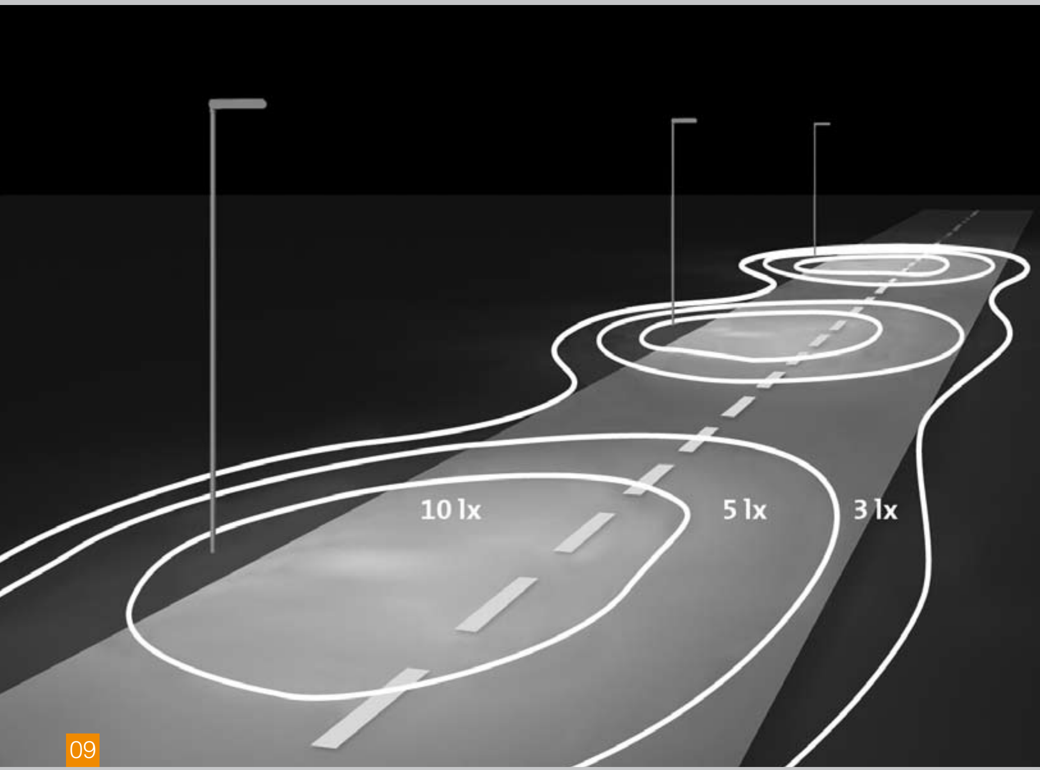

06


07

Lighting situations according to DIN EN 13201

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
A1				Slow moving vehicles, cyclists, pedestrians	Motorways and roads for motor vehicles only
A2	> 60 km/h	Motorised traffic	Slow moving vehicles	Cyclists, pedestrians	Major country roads, poss. with separate cycle- and footpaths
A3			Slow moving vehicles, cyclists, pedestrians		Minor country roads
B1		Motorised traffic, slow moving vehicles	Cyclists, pedestrians		
B2	30 - 60 km/h	Motorised traffic, slow moving vehicles, cyclists	Pedestrians		Trunk roads, through roads, local distributor roads
C1	5 - 30 km/h	Cyclists	Pedestrians	Motorised traffic, slow moving vehicles	Cyclepaths, cycle/footpaths
D1		Motorised traffic, pedestrians		Slow moving vehicles, cyclists	Motorway service areas
D2			Slow moving vehicles, cyclists		Station forecourts, bus stations, car parks
D3	5 - 30 km/h	Motorised traffic, cyclists	Slow moving vehicles, pedestrians		Local access and residential streets, 30 km/h-zone streets (mostly with footpath)
D4		Motorised traffic, slow moving vehicles, cyclists, pedestrians			Local access and residential streets, 30 km/h-zone streets (mostly without footpath)
E1				Motorised traffic, slow moving vehicles, cyclists	Pedestrian and shopping precincts, footpaths
E2	Walking speed	Pedestrians	Motorised traffic, slow moving vehicles, cyclists		Pedestrian and shopping pre-cincts with loading and feeder traffic, traffic-calmed zones (home zones)

08



09


10

Lighting class planning aid
The "Lighting class planning aid" checklist helps the designer compile the information needed to select a lighting class. The different lighting class requirements are clearly listed under 3 main parameters. Before the checklist is used, a lighting situation between A1 and E2 (see table 08, page 11) should be established. The letters A-E in brackets indicate which fields are relevant for which lighting situation.

Standard tables: assessment criteria according to DIN 13201-1 and DIN EN 13201-2
- Average traffic volume
- Intersection density – lots of closely spaced intersections increase the risk of collisions
- Difficulty of the navigational task, e.g. where the presence of different road users travelling at different speeds means that analysing information calls for more attention than usual
- Physical traffic-calming measures need to be reliably identified.

Supplementary tables: assessment criteria according to DIN 13201-1 and DIN EN 13201-2
The supplementary tables include more assessment criteria for classifying roads. These may raise the requirements which the lighting needs to meet:
- Conflict areas (intersections, roundabouts)
- Vehicle sparked at the side of the road
- Complexity of the visual field (advertising hoardings, media facades, etc.)
- Ambient luminance, e.g. bright floodlighting for a nearby sports facility that could interfere with visual perception on the road
- Facial recognition, permitting early anticipation of the intentions and behaviour of approaching persons
- Crime risk – this is factored into planning by comparing the crime rate in the immediate vicinity of the road to the crimes rates in the wider area around it.

Additional data for calculating road lighting in line with DIN EN 13201-3
- Manufacturer, type, lamping and intensity distribution curves of the luminaires
- Maintenance factor of the lighting installation
- Details of the geometry of the road, cross-section of the road or location plan with dimensions
- Definition of the relevant areas
- Details of the positioning of luminaires, with distance from the road
- Mounting height of the light sources.

Maintained values
As a lighting installation's time in service increases, illuminance and luminance decrease due to aging and soiling of lamps, luminaires and reflective surfaces. Maintained illuminance in this context is the average value below which illuminance must not fall. To compensate for the decrease in illuminance, the installation needs to be designed for higher illuminance when it is new (value on installation). In lighting design, the decrease in illuminance is taken into account by the maintenance factor and applied in the equation:
Maintained Value = Maintenance Factor x Value on Installation

To ensure that the minimum illuminance required for the visual task is actually provided under operating conditions, the illuminance and luminance values recommended in the relevant standards are defined as maintained values.

Maintenance factor
In lighting design, a maintenance factor is applied from the outset to guarantee standard-compliant illuminance throughout an installation's service life. A maintenance factor of 0.8, for example, means that the 100% luminous flux on installation will decrease to 80% by the end of the maintenance interval. The maintenance factor (MF) is the product of:
- Lamp Survival Factor (LSF)
  This allows for lamp failure over an installation's service life
- Lamp Lumen Maintenance Factor (LLMF)
  This allows for the decrease in lamp luminous flux over an installation's service life
- Luminaire Maintenance Factor (LMF)
  This allows for the accumulation of dirt on a luminaire's optical systems. It depends

on the IP (Ingress Protection) rating of the luminaire, the level of exposure to dirt from the environment and the cleaning intervals defined (a four-year interval is standard)

- Room Surface Maintenance Factor (RSMF) This allows for the decrease in reflectance of ceiling and walls, e.g. in pedestrian underpasses, tunnels, etc.

MF = LSF x LLMF x LMF x RSMF

As a matter of principle, the designer of a lighting installation must specify a maintenance factor and list all the assumptions made to define it. In addition, a comprehensive maintenance schedule needs to be prepared, setting out both a lamp replacement interval and an interval for cleaning the luminaires and identifying the cleaning methods that should be used.

[09, 10] Uniform illuminance of the road and avoidance of dark patches are important criteria for standard-compliant lighting.

[11] The planning aid provides a template for compiling the information needed to identify the lighting class.

Lighting class planning aid

Parameter	Options	Answers
Area (geometry)		
Separation of carriageways (A*)	yes	☐
	no	☐
Types of junctions (A)	interchanges	☐
	intersections	☐
Interchange spacing, distance between bridges (A)	> 3 km	☐
	≥ 3 km	☐
Intersection density (A, B)	< 3 intersections / km	☐
	≤ 3 intersections / km	☐
Conflict area (A, B)	yes	☐
	no	☐
Physical traffic-calming measures (B, C, D)	yes	☐
	no	☐
Traffic use		
Traffic flow of motor vehicles per day (A, B)	< 7.000 vehicles	☐
	7.000 - 15.000 vehicles	☐
	15.000 - 25.000 vehicles	☐
	> 25.000 vehicles	☐
Traffic flow of cyclists (C, D)	normal	☐
	high	☐
Pedestrian traffic flow (D, E)	normal	☐
	high	☐
Difficulty of visual task (A, B, D)	normal	☐
	higher than normal	☐
Parked vehicles (A, B, D)	not present	☐
	present	☐
Facial recognition (C, D, E)	unnecessary	☐
	necessary	☐
Crime risk (C, D, E)	normal	☐
	higher than normal	☐
Environmental and external influences		
Complexity of the visual field (A, B, D)	normal	☐
	high	☐
Ambient luminance (A, B, C, D, E)	low	☐
	moderate	☐
	high	☐
Main weather type (A, B) Note: In Germany, the main weather type normally selected is „dry“	dry	☐
	wet	☐

* The lighting situations shown are the ones for which the relevant parameter needs to be assessed.

11

Sustainability and environment

A street light shining into the bedroom at night disturbs our rest. But animals and plants also respond sensitively to artificial light in their night-time habitats. Modern lighting installations significantly alleviate these problems.

"Light pollution" and "light smog" are terms widely used to refer to the light immissions that radiate upwards and brighten the night sky over large conurbations. Artificial light from street lighting, illuminated buildings, floodlighting and luminous advertising have diverse effects on human beings and nature. Under Germany's Federal Immission Control, Act (BImSchG), light immissions are classed as harmful effects on the environment "which, according to their nature, extent or duration, are liable to cause hazards, considerable disadvantages or considerable nuisance to the general public". It is therefore important to take account of these factors right at the lighting design stage.

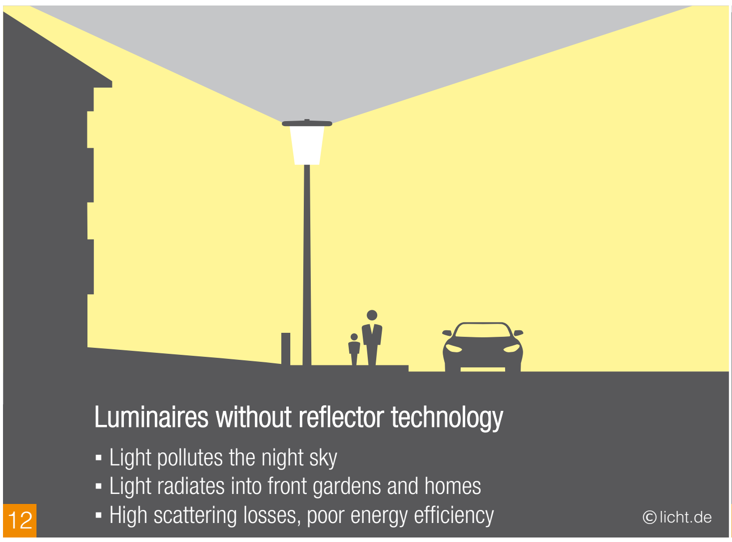
In Germany at present, there are no legal or administrative requirements setting actual limits for light immissions in public street lighting. However, the German Lighting Society LiTG has published details of measurement and assessment methods that can be used to rate immissions as well as proposals for maximum admissible levels (Deutsche Lichttechnische Gesellschaft, Publication No. 17/1998). Further information in German is available at www.litg.de. In addition, the effects of lighting system immissions on residential premises are summarised in the latest 2012 update of the lighting guideline on the measurement and assessment of light immissions developed by the Immission Control Committee of Germany's federal states (Länderausschuss für Immissionsschutz - LAI). The LAI recommends that the methods and ceilings in the guideline should be applied by environmental protection agencies. A number of federal states have already issued "lighting guidelines" on the subject. Several European countries, including the Czech Republic, Slovenia, Italy and Spain have also passed laws to protect the night sky.

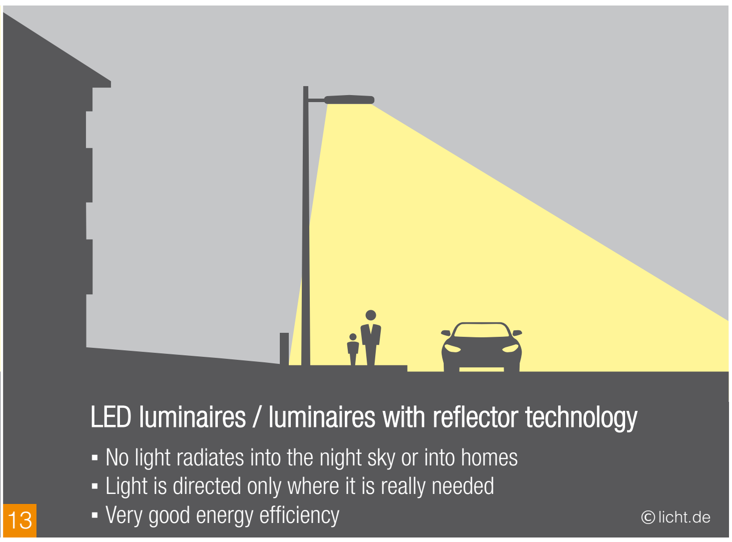
Lightimmissions caused by street lighting can be effectively reduced by using modern street and outdoor luminaires. There are a large number of suitable luminaires on the market. Fitted with energy-efficient light sources (e.g. LEDs) and sophisticated optics, they direct the light to where it is really needed.

Protecting insect habitats

Artificial light attracts insects, so it can severely interfere with their natural habits. Most nocturnal insects respond significantly more sensitively than human beings to the

[12, 13] Sustainable, environmentally sound lighting can only be achieved by luminaires with reflector or LED technology. Light can then be directed precisely where it is needed and unnecessary scattering losses are avoided.





spectral composition and brightness of the light from fluorescent lamps and high-pressure mercury vapour lamps. Pale moonlight, which insects are thought to use for orientation, also appears much brighter to the insect eye than to humans. The light cast by a high-pressure sodium vapour lamp, however, appears darker because most insects are less sensitive to orange and red spectral components. LED light can also be classed as insect-friendly because of the absence of UV radiation (see also Fig. 14).

Positive response to LED luminaires

In the wake of the public lighting competition "Kommunen in neuem Licht", surveys were conducted, with the support of Germany's Federal Ministry for Education and Research (BMBF), to measure acceptance of LED street lighting. In comparisons with conventional technology, LED solutions were invariably preferred. They won high public acceptance, particularly for colour fidelity, perceived brightness and sense of security.

Saving electricity – lowering carbon emissions

Every kilowatt-hour of electricity saved reduces the amount of carbon dioxide pumped into the atmosphere. So saving energy also helps mitigate climate change. The European Commission has set ambitious goals in this respect. In its "Roadmap for moving to a competitive low carbon economy in 2050", it looks at new ways to lower greenhouse gas emissions by 80 to 95 percent.

High carbon savings with LED

In a study published in August 2011, the consulting firm McKinsey demonstrates that LED-based lighting solutions offer the greatest carbon saving potential of all climate protection options for future developments in the lighting industry. The study concludes that the cost of saving one metric ton of carbon dioxide a year by energy-efficient lighting is five times less than the cost of achieving the same reduction through the use of solar installations.

Ecodesign Directive (ErP)

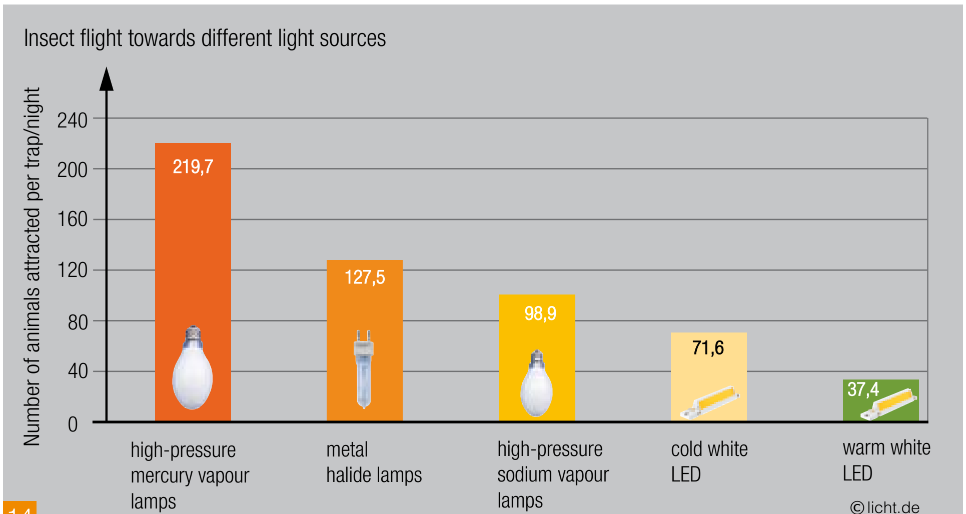
On 20 November 2009, the ErP Directive (Energyrelated Products) – also known as the Ecodesign Directive –came into force to replace the existing EuP Directive (Energy using Products). It sets out ecodesign requirements for all products that have an impact on energy consumption. Under it, every manufacturer is required to make technical product information available in accompanying documentation as well as on the Internet. The primary aim is to remove obsolete fluorescent lamps, high-pressure discharge lamps (especially high-pressure mercury vapour lamps) as well as inefficient control gear gradually from the market.
The first stages of the EU regulation have already been implemented in Germany with the phase-out of inefficient fluorescent and incandescent lamps. Street lighting needs to meet special requirements, such as only using lamps with high luminous efficacy. Municipal authorities are thus called upon to switch from obsolete lighting installations to energy-efficient technologies such as LED.

Disposal of spent lamps and luminaires

The German Electrical and Electronic Equipment Act (ElektroG) regulates the return and environmentally safe disposal of electrical and electronic equipment. Responsibility for this resides with manufacturers and importers, who can assign the task to third parties. Further information is provided by the German Electrical and Electronic Manufacturers' Association ZVEI at www.zvei.org. Spent lamps and luminaires used in street lighting are accepted in Germany by the joint venture Lightcycle Retourlogistik und Service GmbH (www.lightcycle.de). Local retailers and tradesmen also help ensure proper disposal.

Harmful substances in lamps

The Restriction of Hazardous Substances Directive revised in May 2011obliges manufacturers of lighting equipment in the EU to ensure that harmful substances such as lead, mercury, nickel or cadmium are used only in specified, minimal quantities.



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[14] Study by Prof. Dr. Gerhard Eisenbeis on the insect compatibility of LEDs in comparison to conventional light sources. The researcher looks at the behaviour of insects around six different light sources. During the period of the study (summer 2011) in Frankfurt am Main, the light sources tested were placed in receptacles and the insects caught in them were counted each day. The types of lamp used were as follows:
- high-pressure mercury vapour lamps
- metal halide lamps
- high-pressure sodium vapour lamps
- cold white LED
- warm white LED

Productquality

Exterior luminaires are capital goods, in many cases with a service life of well over 20 years. Importance should always be attached here to long-life, high-quality products. Otherwise, the purportedly more economical product will, in the long run, turn out to be the much more expensive option.

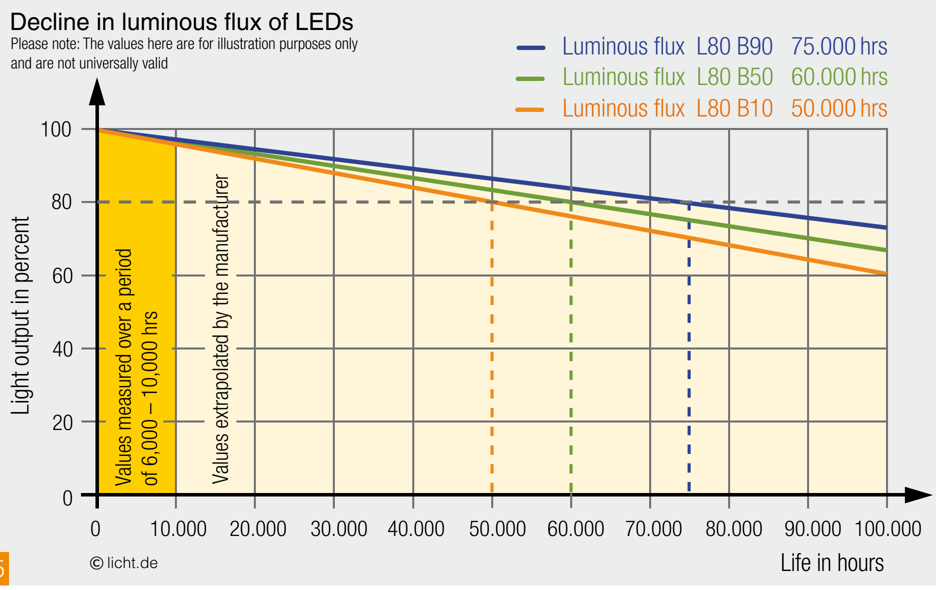
To identify the right luminaire for the job, the lighting designer first needs to look at actual luminaire performance characteristics: luminous flux, power consumption, lifespan, maintenance factor, anticipated decline in luminous flux, light output ratio of conventional luminaires/luminous efficacy in lm/W of LEDs, and whether night reduction is possible. The important thing here is always to consider the luminaire system as a whole, not the individual components.

Basis for product selection: product and lighting quality criteria

- High-quality housing material (e.g. aluminium, single-pane safety glass, etc.)
- High-quality coatings and small number of loadbearing plastic parts
- Even years after purchase, LED components should be available in the same lighting quality
- Replaceable standard components
- Good heat dissipation in LED luminaires; the technical data sheet shows the maximum permissible temperature limits.
- A high colour rendering index (R_a), depending on user requirements.
- Constant light colour (in Kelvin) and constant brightness level where a number of luminaires of the same type are to be used
- Good maintenance factor (MF)
- High luminaire luminous efficacy.This should always be appraised in the context of a lighting plan, however, because the light emitted needs to be assessed in the intended environment.
- Appropriate intensity distribution. A basis for decisions here is provided by intensity distribution curves (luminaire data records) and planning support data (e.g. EULUMDAT).
- The power consumption of the luminaire and the anticipated decline in luminous flux. For realistic product comparison, care must be taken to ensure identical framework parameters.

Thermal management

Good thermal management is essential for LED luminaires. LEDs can achieve their long service life and energy efficiency only if they do not overheat in operation. To permit heat dissipation over as large an area as possible, there should



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[15] The longevity rating of LED luminaires and LED components is established by measuring luminous flux and failure over 6,000 hours (luminaires) and 10,000 hours (components) respectively. The lifespan stated for the product is extrapolated by the manufacturer from the data thus obtained. The luminous flux value (L value) must always be indicated in conjunction with operating time. The B value indicates the point by which a certain percentage of components will have failed. Example: B50 indicates the point at which 50 percent of a number of identical LED luminaires fall below the declared percentage of luminous flux (x) at the end of the monitoring time (L). If no B value is indicated, Lx is assumed to be B50. In this case, the entire luminaire is assessed, not just a component or a single LED.

be a thermal connection between the luminaire housing, for example, and the LED circuit board.

Binning

In the manufacture of LEDs, there are always differences within batches in terms of luminous flux, colour temperature and forward voltage. To guarantee constant light quality with the same level of brightness and uniform light colour, LEDs in each batch are binned, i.e. they are sorted and grouped according to their performance characteristics.

Manufacturer-related quality criteria

Certification to DIN/ISO-9001 confirms that a manufacturer's development, manufacturing and distribution processes are geared to quality and that standard complaint procedures are in place.
To ensure high product quality and obtain reliable performance data, the manufacturer should also have its own laboratory or use a professional service provider.

Maintenance factor and soiling

The maintenance factor of a luminaire (see also pages 12-13) takes account of cleaning intervals (four-year intervals are fairly standard). It also depends on environmental soiling, which is divided into the following categories:

- Heavy soiling
  Clouds of smoke and dust, e.g. in industrial zones.
- Average soiling
  High traffic volumes with smoke and dust.
- Light soiling
  Exclusively in residential areas and rural areas with no smoke or dust pollution.

Reliability, guarantee, maintenance

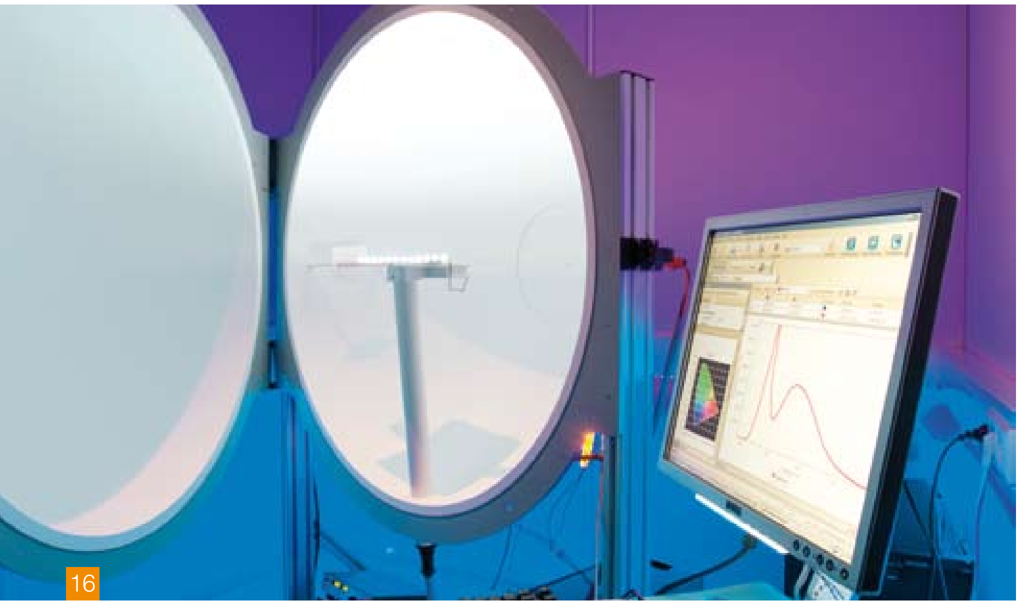
Anyone selecting a luminaire manufacturer should always consider quality and service. The manufacturer has to guarantee the reliability of its products in line with the stipulations of relevant European standards. Because some manufacturers' guarantees are subject to restrictions and are not enforceable if there is a change of dealer, the scope of the guarantee should be clearly stated and should include a binding obligation on the manufacturer. In Germany, assembly instructions and data sheets for reliable installation and assessment must be available and need to be in German for compliance with German law.

Luminaires should naturally be easy to maintain and repair. Before and after-sales service and support ensure conflict-free operation of a lighting installation for many years. Technical and regional support as well as personal contact and training opportunities are also desirable.

Disposal

Even at the acquisition stage, disposal arrangements should be factored into the purchase decision. Manufacturers provide information on recycling, dismantling and waste separation. Care should also be taken to ensure that as little material as possible will constitute hazardous waste on disposal.

www. The ZVEI guide "Planning Security in LED Lighting" offers more information on the subject of product quality. It is available for download as a PDF at www.zvei.org.



[16] The "Ulbricht sphere" permits illuminance to be measured by collecting unevenly distributed luminous flux from all directions. The photometer inside the sphere measures the illuminance in lux and the luminous flux in lumen.

Lighting management

Lighting management systems make it possible for municipal authorities to realise variable and intelligent outdoor lighting solutions. They permit a flexible response to fluctuating traffic volumes, allow luminaires to be individually switched or dimmed and thus significantly lower energy costs in operation.

Lighting management systems in outdoor lighting enable substantial energy-saving potential to be tapped. Each individual light can be activated and deactivated or dimmed as required. In addition, operating condition, energy consumption and failure information is collected and stored on a central computer complete with precise report time and location details. Street lighting operators' efforts to ensure road safety are thus supported by a fine-tuned lighting level. Light failure is also reported immediately. Anticipatory maintenance plans can be prepared in advance and operations thus facilitated.

Tailored lighting

As a result of the increasingly widespread use of electronic operating devices and modern light sources, lighting has become more flexible. Individual lights or groups of lights can be digitally switched or dimmed as required to adapt lighting levels to actual needs and at the same time increase road safety. Lighting levels can be raised when traffic is heavy, where accident risk is high or when the weather is bad and they can be lowered at times when traffic volumes are low.

Lighting management systems reduce deliberately planned over dimensioning and dim, for example, a 150 W luminaire to the required 120 W. This intelligent intervention enables energy consumption to be lowered. It also reduces carbon emissions, cuts maintenance costs and improves reliability.

The advantages at a glance:

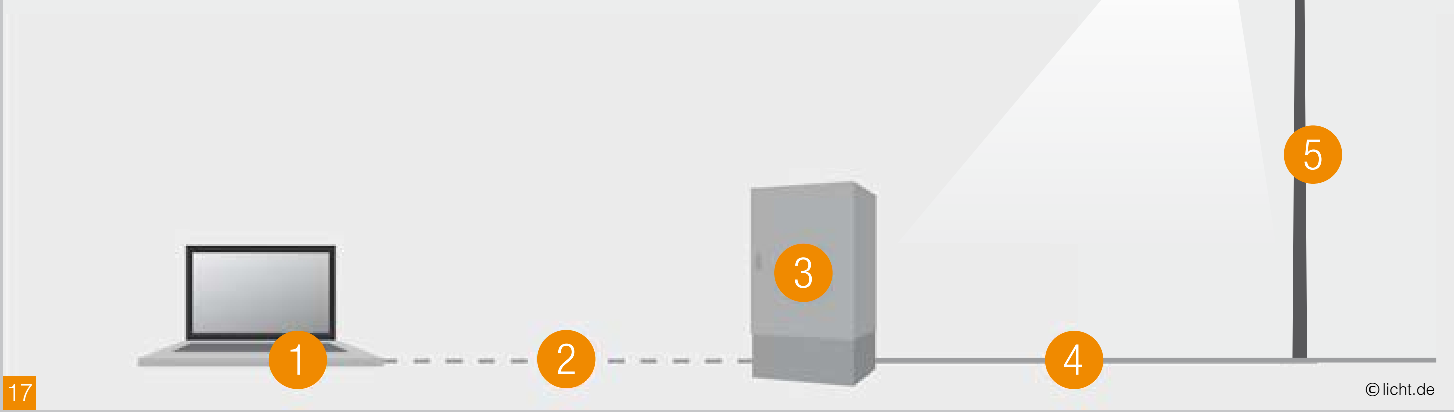
- energy conservation
- lighting level tailored to the situation
- lower greenhouse gas emissions
- more efficient maintenance
- greater safety, damage can be repaired more swiftly.

Apart from cutting energy and maintenance bills, modern lighting management system solutions (LMS) also permit individual luminaire monitoring. For example, it is possible to ascertain whether individual light sources are defective and how much power a luminaire currently consumes. The industry offers lighting management system solutions in various

[17 - 20] There are a wide range of control options for street lighting. Whether control should be autonomous or by powerline or wireless technology is up to the individual operator. Advantages are certainly offered by systems that permit feedback on faults or lamp failure.

Examples of components of a powerline or wireless lighting management system

1 Central server with user software
2 Communication path to the server
3 Luminaire controller communication module
4 Powerline or wireless transmission
5 Coupler and EB/luminaire



configurations. Below is a brief description of the different options with a comparison of their pros and cons.

Autonomous lighting control

The simplest variant is autonomous lighting control, where the control unit is integrated in the ballast. With this stand alone solution, no additional control lines or controllers are necessary. Technically, it works by being fitted with a so-called "astro-clock" programmed with location data. The lighting can then regulate itself autonomously according to the programmed times and lighting level. Depending on the range of features – which varies from one type of luminaire and manufacturer to another – different brightness levels can also be programmed.

The advantage of autonomous lighting control is that no additional components such as control units or control lines are necessary. However, each device needs to be individually programmed. If settings are subsequently changed, each luminaire has to be reprogrammed on site by a specialist. In addition, the system does not provide feedback on failed light sources, etc.

Telemanagement systems

Unlike autonomous lighting control systems, telemanagement systems regulate luminaires from a central control unit. Each luminaire is assigned an address, enabling it to be precisely controlled and monitored. From the central control point, the luminaire controller can be addressed or its programming changed via the Internet. In the other direction, information about the lighting installation, e.g. error reports, can be transmitted for analysis. Data is transmitted between control unit and luminaire or electronic ballast in one of two ways – by powerline communication or by wireless communication.

Powerline communication

In a powerline lighting control system, signals are transmitted via the existing wiring system. They are picked up by an appropriate receiver, which turns them into an exportable form (e.g. DALI). Control is basically only possible with electronic ballasts (EBs), for which the signals are made accessible by a coupling module. A luminaire controller is also required to issue the control commands. The advantages of powerline solutions are maximum flexibility and reliability.

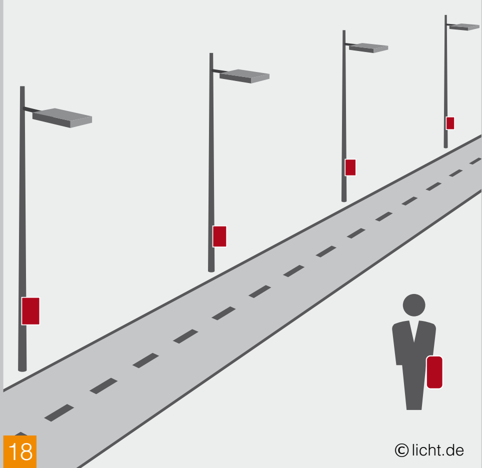
Wireless communication

In contrast to powerline communication, the control signals in a wireless system are not carried by cables but by radio waves. However, the principle is very similar. Here too, a controller is needed to transmit the signals wirelessly to the ballasts. If the ballast does not support the wireless standard, a coupler again needs to be used to translate the wireless signals for the ballast. The couplers also generally serve as repeaters, amplifying the incoming signals, so very remote luminaires can also be controlled.

Data transmission, both by powerline and by wireless technology, is reliable and permits bidirectional communication between controller and luminaire. Reprogramming can be done from a central point. And thanks to a common standard, usage is manufacturer-independent. The technology is fairly complex, however, so installation and programming should be performed by specialist companies.

Autonomous lighting control

- Control is programmed directly at each luminaire
- Only decentralised control possible
- No automatic lamp failure reporting



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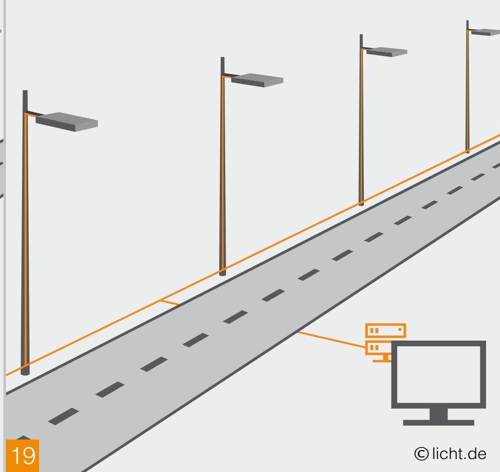
Powerline lighting control

- The existing wiring system is used
- Automatic lamp failure reporting possible
- Control is centralised



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Wireless lighting control

- Control signals transmitted wirelessly
- Network extended by repeaters in the luminaires
- Automatic lamp failure reporting possible
- Control is centralised

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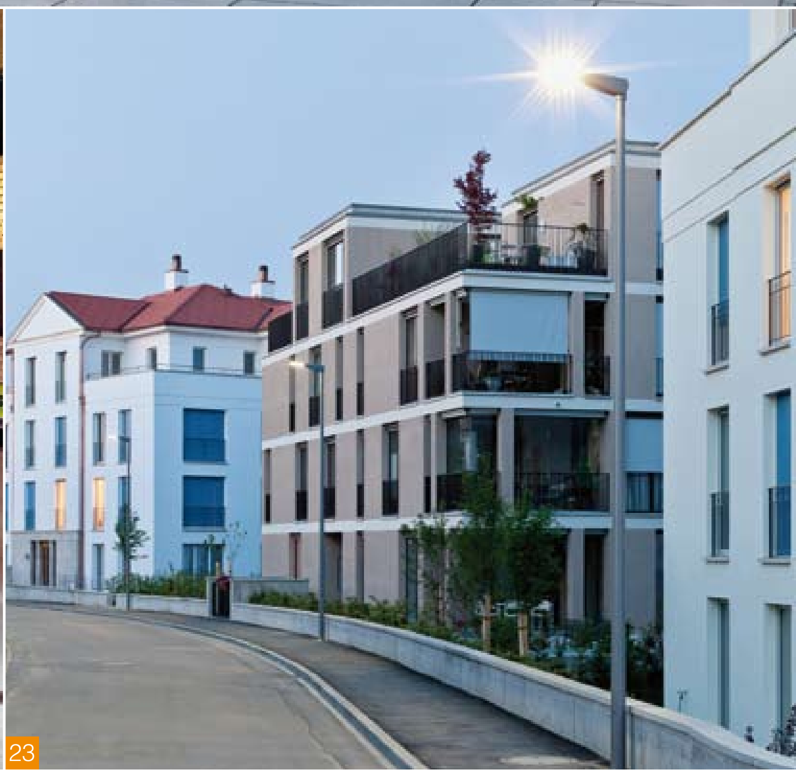

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Side streets and traffic-calmed zones

In local access and residential streets with a speed limit of 30 km/h or less, the primary purpose of lighting is to protect the "weaker" road users, whose accident risk exposure is the greatest. To promote a sense of security for road users on foot, pedestrian area lighting should ensure that passers-by can recognise one another clearly.

Correct lighting is also required – in addition to lower speeds – to help optimise motorists' and cyclists' ability to respond to changing situations. An adequately high and uniform lighting level enables persons and objects that suddenly appear to be perceived more swiftly and accidents thus avoided. The risk of accidents is particularly high in local access and residential streets without footpaths.

Local access and residential streets are assessed on the basis of average and minimal illuminance. The average illuminance required ranges from 2 to 15 lux, depending on the individual situation. Traffic-calming measures, parked vehicles and navigation task category are typical selection criteria that need to be considered separately. But lighting needs to illuminate more than just the roadway. It must also provide sufficient illuminance for adjacent areas. At the same time, care must be taken to avoid light pollution that would impinge on residents' quality of life. Modern LED luminaires, for example, illuminate only the relevant area of the road or cycle/foot path. Light scattered in the direction of residents' windows and gardens and light emitted in the direction of the sky are thus reduced to a minimum.

Light makes for greater security

In addition to road safety, a local authority's duty of care towards citizens includes curbing crime risk. Good lighting heightens the subjective sense of security felt by passers-by and residents. Reliable recognition of persons also helps enable us to prepare for and respond to dangerous situations more swiftly. Criminals shun bright light for fear of being identified. 2 to 15 lux average illuminance and 0.5 to 3 lux semi-cylindrical illuminance, measured at 1.5 m above the ground, ensure the required degree of security and comfort.

[21, 22] Lighting in traffic-calmed zones creates an agreeable atmosphere and a sense of security. During the day, the luminaires are perceived as part of the urban landscape and can thus positively influence a town's image.

[23, 24] Modern, energy-saving LED street luminaires are not only better for the environment; they also have particularly low maintenance requirements.

Assessment criteria

Local access and residential streets, 30 km/h zones with or without footpath (lighting situations D3 and D4 according to DIN 13201):

- Local access and residential streets are assessed on the basis of average and minimum horizontal illuminance.
- Depending on the local situation, 2 to 15 lux average illuminance is required.
- Traffic-calming measures, parked vehicles and navigation task category are typical selection criteria that need to be considered.
- 0.6 lux to 3 lux minimum illuminance is needed to achieve the required uniformity.
- 0.5 to 3 lux semi-cylindrical illuminance is appropriate. It facilitates recognition of approaching persons and helps reduce crime.

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Trunk roads

Clearly visible from a plane at night, trunk roads run through our towns and cities like arteries in the human body. Viewed up close, they clearly need good lighting, especially to ensure the safety of all road users.

Traffic on trunk roads, through roads and local distributor roads as well as in built-up areas is characterised largely by the fact that it consists of many different main users. There is schoolchildren waiting for the bus, employees on the way to work by car or bike and HGVs delivering fresh stock for supermarkets. They all need well-lit roads, cycle tracks and footpaths so they can be seen by other road users and can themselves recognise objects and obstacles reliably and in good time.

To create and compute a good, standard-compliant lighting installation, it is necessary to consider a whole range of criteria. If the street space is used by motorists, cyclists and pedestrians together, lighting needs to be assessed and designed in a very different way than if cycle tracks and footpaths are separate. Other crucial factors are the safety of the road itself, distractions for road users due to shop windows, neon advertising, etc. and the speed at which motor vehicles travel.

For standard-compliant lighting, the first thing that needs to be established is what special features and circumstances are present and how they impact on lighting requirements.

The following questions need to be answered:

- Who are the main users?
- Are physical traffic-calming measures in place?
- Is visibility obstructed by parked vehicles?
- How difficult is the navigational task?
- Are there bends or inclines?
- Are there conflict areas?
- How high is intersection density?
- How complex is the visual field?

For higher lighting requirements, DIN 13201-1 includes a detailed selection matrix with which the required lighting level can be defined.

The lighting assessment criterion for trunk roads is roadway luminance from the vantage of the observer. It depends on the position of the luminaires, the luminous flux of the lamps, glare control and the reflectance of the road surface.

To ensure lighting uniformity, the brightness of cycle tracks and footpaths needs


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to be geared to the brightness of the roadway. In the case of roads with no adjoining traffic areas, a balanced ambient illuminance ratio makes for better orientation.

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[25-27] Good trunk road lighting makes for safety. The lighting level needs to be tailored to users' needs and conflict areas or hazards must be highlighted.

Assessment criteria

Trunk roads, through roads, local distributor roads (lighting situations B1 and B2 according to DIN 13201):

- The assessment criterion for trunk road lighting is mean roadway luminance. In conflict areas or on bends or short sections of road, mean illuminance and illuminance uniformity are used instead.
- 0.3 to 2 candela/m² luminance is required, depending on the local situation.
- Selection criteria to be considered: ambient illuminance ratio, side-switching parking bays, shopping streets, difficulty of the navigational task.
- DIN 13201-1 includes a detailed selection matrix for higher lighting requirements.
- Roadway boundaries and areas adjacent to the roadway (e.g. cycle tracks and footpaths) require an adequate level of illuminance, which depends on the minimum roadway luminance required.
- Where there are no traffic areas adjacent to the roadway, attention must be paid to ensuring a balanced ambient illuminance ratio.
- Other parameters such as overall and longitudinal uniformity as well as veiling luminance also need to be considered.

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Assessment criteria

Motorways and roads for motor vehicles only (lighting situations A1, A2, A3 according to DIN 13201):

- Mean roadway luminance is the lighting assessment criterion for motorways and roads for motor vehicles only. The following factors have a bearing on the perceived brightness of the roadway:
  - position of the observer
  - reflectance of the road surface
  - arrangement of luminaires
  - intensity distribution of luminaires
  - luminous flux of lamps
- Appropriate overall and longitudinal uniformity of the light distributed.
- Adequate glare control taking account of the permissible threshold increment (TI).
- To permit better orientation, the ambient illuminance ratio needs to be right for the mean roadway luminance.
- An adequate ambient illuminance ratio needs to be observed to gear the brightness of roadway boundaries and areas adjacent to the roadway (lighting situations A2 and A3 only), e.g. cycle tracks and footpaths, to the brightness level of the road.

Motorways and roads for motor vehicles only

High speed requires particularly good visibility. The three main criteria for street lighting that promotes safety and thus reduces accidents are brightness, uniformity and glare control. The rule of thumb is: the brighter the street, the better the motorist recognises obstacles and dangerous situations.

On motorways, expressways and secondary roads, high speed is the order of the day. However, there are also slower vehicles on these roads, such as HGVs or cars with trailers. So, street lighting here needs to provide optimal support for navigational tasks so that traffic accidents resulting in injury can be avoided as far as possible.

Greater safety is achieved, in particular, by ensuring that the road ahead, along with any hazards or obstacles, is visible from a good distance. Adequate roadway brightness, uniform illumination and avoidance of glare go a long way to ensuring safety.

Roadway brightness

Roadway brightness is the first crucial requirement for good visibility. It depends on various factors, such as the reflectance of the road surface, the luminous flux of lamps and the arrangement and intensity distribution of luminaires.

Uniformity

A uniformly illuminated street with minimised patches of shadow and darkness helps road users move around safely on the roads at night. Where ambient luminance is higher because of bright areas – e.g. shop windows, brightly illuminated facades or squares – the roadway luminance needs to be adjusted accordingly so that persons, vehicles and objects are recognised in good time.

T-junctions or hazard areas need to be highlighted and thus made safer by means of higher illuminance. Transitions from brightly illuminated to less well lit or even unlit road sections should be gradual because the human eye needs a little time to adapt to darkness. In the other direction, i.e. from dark to light, our eyes adapt much faster.

Avoidance of glare

Any risk of motorists being dazzled by lighting needs to be totally ruled out. Glare assessment is based on a predefined viewing direction for the motorist. DIN EN 13201 also regulates the permissible percentage threshold increment (TI), which is the yardstick for assessing physiological (disability) glare.

[28, 29] Motorway access points are particularly prone to accidents. Column luminaires with a high mounting point help motorists filter safely into moving traffic.

[30] On busy stretches of motorway, lighting helps motorists get their bearings and ensures greater safety.

Pedestrian precincts and squares

Squares and pedestrian precincts are hubs of city life, places where people go to see and be seen. Restaurants, bars, cinemas and shops invite residents and tourists to shop, stroll, tarry, enjoy a meal or drink and unwind.

Lighting for downtown areas such as pedestrian precincts and squares needs to be designed, on the one hand, to provide safety for passers-by and help them get their bearings. On the other, it should help create a welcoming, appealing atmosphere that draws people into the town or city and gives them a sense that they are in an attractive place where they feel comfortable. Where accentuated light is used to highlight a building, artwork or landmark, for example, it shows a city coming to terms with its history, with its social and cultural responsibility. It thus fuels civic pride. Bright, attractively designed squares help generate business for shops and restaurants and at the same time lower crime risk.

But luminaires are also an important element of urban architecture. Whether design-oriented and low-key or eye catchingly ornate, the physical appearance of luminaires helps shape the face of a city during the day.

Environmental protection

Environmental protection is also an issue when it comes to choosing the right luminaires. It is important to minimise scattered light – "light smog" – by the use of energy-efficient, environmentally sound luminaires and light sources as well as by choosing colour temperatures that are less attractive to nocturnal insects and animals. Precise optical control prevents scattered light in the direction of the sky and thus stops light causing a nuisance by radiating unnecessarily into homes. Quality luminaires with modern LED technology and intelligent control reduce energy consumption and operating costs.

Where events are held in pedestrian precincts and squares, the Ordinance Governing Places of Assembly (VStattVO) needs to be observed with its safety lighting requirements for escape routes, exits and steps.

Stairs and steps

To avoid accidents, stairs and steps need to be clearly perceivable even in twilight or at night. Wall, bollard or column luminaires with modern reflector technology make it possible to focus light largely on hazard areas. Where installation is possible, dedicated step lighting is recommended, e.g. with recessed LED luminaires.

Assessment criteria

Pedestrian and shopping precincts, footpaths (lighting situation E1 according to DIN 13201).Lighting situation E2 applies to pedestrian and shopping precincts where delivery and feeder traffic is permitted as well as to traffic-calmed zones (home zones):

- The relevant lighting requirements can be ascertained by following the selection procedure set out in DIN 13201-1 and applying the special decision criteria it requires.
- The assessment criterion for lighting where only pedestrian traffic is present is average horizontal illuminance. The maintained illuminance here should be between 2 lux and 20 lux. Over the assessment field, a minimum of 0.6 lux to 5 lux is requiredwith uniformity at 0.4 (for 20 lux).
- People and their faces can be rendered clearly discernible by ensuring that minimum semi-cylindrical illuminance is 0.5 lux to 5 lux.
- Lighting for stairs, e.g. at railway stations, is covered in DIN EN 12464-2. For stairs that are only occasionally used, 5 lux is sufficient; for busy stairs, however, up to 100 lux is stipulated. Uniformity needs to be at least 0.25 to 0.50.

[31] In the evening and at night, the *Universitätsplatz* in Fulda – winner of the German Lighting Design Award in 2013 – comes to life and acquires a whole new recreational quality thanks to its zonal lighting. Systematic facade lighting emphasizes the vertical surfaces and creates an agreeable sense of space.

[35] People come to pedestrian precincts to shop, have a leisurely coffee or simply stroll around. The right lighting ensures that safety and easy orientation are guaranteed.

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Square lighting variants

Conveying a sense of security [32]: A carpet of light created by luminaires positioned at the periphery uniformly brightens the square and ensures that people can be clearly made out and everyone feels safe. Glare is avoided by arranging mounting heights outside the visual field of passers-by.

Creating atmosphere [33]: Diverse low-mounted lights arranged in groups make for a relaxing and agreeable atmosphere. Special features such as trees or monuments are emphasized by bright zones and thus hold a special attraction for passers-by. In this example, the upper parts of the surrounding building facades remain dark and retiring because of the mounting heights of the luminaires.

Setting the scene [34]: The facades of the buildings at the edge of the square and special local features such as fountains or monuments are specifically and dramatically highlighted. Architectural elements on the facades are thus picked out in detail. The floor of the square in this case recedes and is mainly illuminated by light reflecting from the walls. Individual dots of light and bright zones draw the eye of the observer and make for a stimulating atmosphere.


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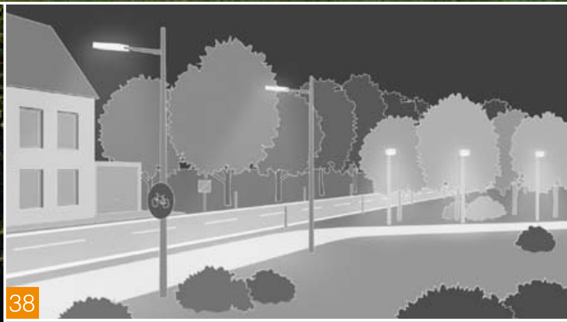

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Cycle path lighting

Good cycle path lighting [38] significantly reduces the risk of accidents in twilight or at night. To avoid collisions, cyclists need to be able to make out other road users, pedestrians and obstacles from a good distance. Within built-up areas, cycle path lighting is often provided by general street lighting. However, suitably wide-angled light distribution is needed to prevent the creation of dark patches. Cycle paths away from roads, in parks or gardens need a dedicated lighting solution tailored to cyclists' requirements. It should facilitate orientation, mark paths and reveal the condition of the path surface. When choosing luminaires, care needs to be taken to ensure appropriate mounting heights, light colour and optical control. The illuminance values required for standard compliance are shown in the last bullet point under "Assessment criteria" on the right.

Parks and gardens

Parks and gardens signal an attractive urban environment offering quality of life. Lighting heightens their appeal by showcasing their features while also facilitating orientation and ensuring safety.

Parks and gardens are hailed as the "green lung" of a city. But apart from their role as an ecological asset, they also have an important emotional function. They invite us to relax and to exercise and they improve quality of life in an environment dominated by buildings and streets.

Creating a greater sense of safety

When night descends, the positive appeal of parks and gardens can quickly turn into the opposite. We all know the uncomfortable feeling of having to walk home in twilight or at night through a poorly lit park. Artificial lighting cannot convey the same sense of security that we feel during the day but it can go some way towards enabling us to move around safely in a park after dark and also to make an assessment of people coming towards us. What helps us do that is standard-compliant semi-cylindrical illuminance, which makes facial features clearly recognisable (see also the grey box on assessment criteria as well as Fig. 53 on page 39).

Obstacles need to be identifiable

Lighting that marks the route of paths in a park facilitates orientation and helps us find our way more easily. Illuminance over the assessment field here should be at least 0.6 lux to 8 lux so that pedestrians, cyclists, skaters and scooter riders can make out the condition of the paths and identify obstacles and differences in level.

Emotional appeal for visitors

Decorative function of luminaires

Decorative lighting in urban parks and gardens plays an important role in modern city marketing. Visitors are addressed on an emotional level and can experience urban quality of life through into the night – because when trees, walls, sculptures, fountains and buildings are illuminated, a very special lighting atmosphere is created. Bathed in accentuating light, special features stand out from their surroundings; they become luminous eye catchers.

During the day, luminaires perform a decorative function, which should not be underestimated. They define the style of the surroundings. A clear, simple design would not be right for a baroque garden, for example, but it suits a clearly structured park.

licht.de booklet 16 "City Marketing with Light" is packed with examples showing how lighting can be used to enhance the urban landscape.

Assessment criteria

Lighting situation E1 (according to DIN EN 13201-1) applies to parks and gardens where motorised traffic is not allowed and E2 (according to DIN EN 13201-1) where cyclists and slow moving vehicles are permitted:

- For pedestrian traffic alone, the lighting assessment criterion to be applied is average horizontal illuminance. Maintained illuminance here should be between 2 lux (E1) / 3 lux (E2) and 20 lux. Over the assessment field, a minimum of 0.6 lux to 5 lux should be achieved with uniformity at 0.4 (for 20 lux).
- The lighting level of these installations also depends on ambient brightness.
- If footpaths feature stairs or steps or if their surface is uneven, a higher lighting level is necessary.
- Semi-cylindrical illuminance should be at least 0.5 lux to 5 lux to enable persons and their faces to be recognised from a distance. It should be measured at a point 1.5 m above the ground.
- Cycle paths are classed as lighting situation C1 according to DIN 13201-1. Depending on ambient brightness and traffic load, the average maintained horizontal illuminance should be 2 lux to 15 Lux. Over the assessment field, the minimum must be no lower than 0.6 lux to 3 lux.

[36] Accent lighting casts plants and fountains in a particularly dramatic light at night.

[37] Lighting makes for safety, especially in parks and dark places. High semi-cylindrical illuminance enables people and faces to be recognised more swiftly and accurately.

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Station forecourts, bus stations and car parks

These are often places where first impressions are made on visitors. But they are not always the best calling card for a city. With the right light, the interfaces of public and personal transport become more attractive and safer.

In any community, even groups that fail to agree on anything else generally agree that public transport should be made more attractive. But doing so involves more than just developing the right fare structures and timetables; it also means ensuring that the relevant public spaces – station forecourts and bus stations – are served by attractive, safe and functional lighting. To enable passengers and drivers to get their bearings reliably, dedicated lighting is needed to make the entire facility stand out from the surroundings. Supplementary lighting can also be used to mark stopping areas and especially to enable passengers to identify differences between floor and ground level so that they can board or alight safely.

Sense of safety – especially safety from crime – is also an important factor defining how we experience time spent at a bus or train station. Depending on the level of crime risk, a higher lighting level may be required. Perception and recognition of faces are facilitated by ensuring that semi-cylindrical illuminance is no lower than 1.5 lux to 5 lux. Whether the illuminance should be lowered at night to save energy needs to be weighed up against the risk of criminal assault. As a rule, station forecourts and bus stations are standard lighting situations D1/D2 – more on that in the grey box.

Car parks: Preventing accidents takes priority

In car parks, where motorists and pedestrians are both present, road safety and accident prevention are even greater priorities. Here too, lighting needs to facilitate orientation – to help motorists find a parking space and their parked vehicles after dark. Lighting needs to create sufficiently good visual conditions to avoid collisions between moving and parked vehicles, pedestrians and obstacles such as trees or bollards. Special hazards are found at entrances, exits and any other points where the different traffic streams meet. They can be highlighted by an appropriate arrangement of luminaires. Safety from crime is

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also an issue in car parks: an adequate lighting level with high vertical illuminance guards against vehicle break-ins and theft and lowers the risk of physical assaults.

LED technology offers advantages

The advantages of luminaires with LED technology have also been demonstrated for these lighting applications. They reduce light pollution, they offer flexible light distribution, they are intrinsically efficient and their brightness – and thus power consumption – can be regulated as required by a lighting management system. Typical solutions are column luminaires with mounting heights up to 4.5 metres for small car parks and up to 12 metres for large ones.

[39, 40] A heightened lighting level provides a greater sense of security and makes for better passenger orientation at bus stations, on station forecourts and in car parks.

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Assessment criteria

Bus stations and station forecourts [41] (lighting situation D2 according to DIN 13201):

- The relevant lighting requirements are established by following the selection procedure set out in DIN 13201 1 and by applying special decision criteria for traffic routes and areas.
- The lighting assessment criterion for bus stations and station forecourts is average horizontal illuminance. Maintained illuminance needs to be 7.5 lux to 20 lux. Over the assessment field, at least 0.6 lux to 7.5 lux is required.
- Good perception of people and faces is achieved by ensuring adequate semi-cylindrical illuminance of 1.5 lux to5 lux.
- DIN EN 12464-2 for workplace lighting is used for stair lighting in outdoor public areas such as stations. For stairs that are only occasionally used, 5 lux is sufficient; for busy stairs, however, up to 100 lux is stipulated. Uniformity needs to be at least 0.25 to 0.50.

Car parks [42] (DIN EN 12464-2 or lighting situation D2 according to DIN 13201):

Stipulations for average maintained horizontal illuminance in car parks are as follows:

- DIN EN 12464-2 stipulations:
  - 5 lux (U0 ≥ 0.25) where traffic density is low
  - 10 lux (U0 ≥ 0.25) where traffic density is moderate
  - 20 lux (U0 ≥ 0.25) where traffic density is high
- DIN EN 13201 stipulations:
  - 5 lux (Emin> 1 lux) for e.g. S4 lighting class
  - 10 lux (Emin> 3 lux) for e.g. S2 lighting class
  - 20 lux (U0> 0.40) for e.g. CE2 lighting class
- Good perception of people and faces is achieved by ensuring adequate semi-cylindrical illuminance of at least 1.5 lux to 5 lux.

Pedestrian crossings and street crossing aids

Strict lighting standards ensure that we can cross the road safely at a pedestrian crossing at night. Supplementary lighting providing high vertical illuminance is obligatory here. It is also a proven solution for street crossing aids, for which the regulations are less strict.

The “zebra crossing”, as the pedestrian crossing is colloquially known, is a child of the economic miracle. As motor traffic increased, so too did the need to make it possible for pedestrians to cross the road safely at designated points. The design of pedestrian crossings is very precisely regulated by law, not only with regard to the markings on the road and the identifying sign 293 of the German Road Traffic Ordinance (StVO) but also as far as lighting is concerned – because the safety of pedestrians crossing the road naturally also needs to be guaranteed at night. Guidelines for the construction and configuration of pedestrian crossings apply throughout Germany (*“Richtlinien für die Anlage und Ausstattung von Fußgängerüberwegen (R-FGÜ 2001)”*).

Vertical illuminance required

While light-controlled pedestrian crossings – ‘pedestrian lights’ – are treated for lighting purposes as a conflict area, crossings identified by StVO sign 293 need are governed by special rules. Pedestrians using them need to be clearly recognisable from both traffic directions, including at night or when the road is wet from rain – and not only on the crossing itself but also in the waiting areas. So supplementary, stationary lighting is normally required and needs to comply with the design requirements set out in the standards DIN 13201 and DIN 67523.

Vertical illuminance is needed to make persons stand out brightly against the background. At pedestrian crossings, it is provided by asymmetrical luminaires positioned so that both crossing and waiting areas are illuminated from the relevant direction of travel. A light colour that contrasts with the rest of the street lighting makes for even greater visibility. In the past, monochromatic yellow low-pressure sodium vapour lamps were used for this purpose, then high-pressure sodium vapour lamps; today the requirements can be effectively and sustainably met using dedicated LED pedestrian crossing lights. It is not permissible to deactivate the supplementary lighting at night. The only instance in which accentuating light is not required for a pedestrian crossing is where the requirements of lighting class ME2 are met at either side of the crossing over a fairly long stretch of road throughout the night.

Street crossing aid lighting: not a must but highly recommended

Where a street does not meet the requirements for a ‘proper’ pedestrian crossing, so-called crossing aids can be provided to help pedestrians cross the road. They include measures such as narrowing, raising or dividing the carriageway. Lighting is not mandatory but, according to the “Recommendations for pedestrian crossing aids” published by the DIN standards committee FNL 11, DIN EN 13201-compliant lighting improves perception in such areas for all road users.

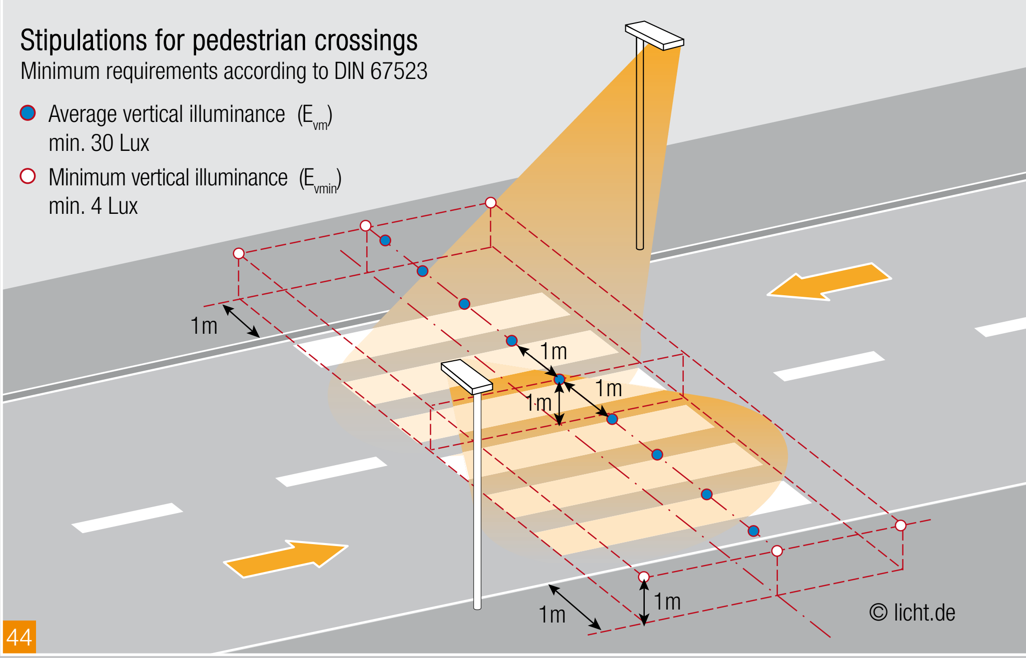
[43] Pedestrian crossings are particularly important for children and young teens as well as for older people. Standard compliant lighting guards against serious accidents, especially in twilight or at night.

43

Normative guideline values and stipulations for pedestrian crossings

In pedestrian crossing lighting [43, 44] the focus is on vertical illuminance and contrast to ensure that pedestrians in a waiting area or on the crossing stand out from the background. Pedestrian crossings are dealt with in the annex of DIN EN 13201-2, which also refers to the national standards of the individual member states. In Germany, the pedestrian crossing guidelines R-FGÜ 2001 (Richtlinien für die Anlage und Ausstattung von Fußgängerüberwegen) and DIN 67523 "Lighting of pedestrian crossings (sign 293 StVO) with additional lighting" need to be observed:

- If the existing street lighting fails to reach the values required in the standards, stationary supplementary lighting needs to be installed.
- To ensure uniform assessment of the lighting at pedestrian crossings, a rectangular, horizontal assessment field is agreed (see also Fig. 44):
  - 30 lux maintained illuminance is required at defined points on the central axis 1 m above the ground.
  - Illuminance must be no lower than 4 lux at any of the defined assessment points in the assessment field, not even in the waiting area 1 m away from the road.



44

- The lighting must illuminate the pedestrian crossing and the adjacent waiting areas "from the relevant direction of travel" – lighting directly above the central axis of the crossing is not permitted.
- A different light colour from that of the general street lighting makes for greater visibility.
- Pedestrian crossing signs can double as lighting.
- In contrast to street lighting, pedestrian crossing lighting may not be deactivated at any time during the night.
- For 100 metres on either side of a pedestrian crossing, the luminance of the road needs to be at least 0.3 candela/m². If necessary, the level of the existing street lighting needs to be raised accordingly.
- Pedestrian crossing lighting needs to be separately switchable.

Conflict areas

Where different streams of road users travelling at different speeds come together, there is a risk of conflict, even collision. At crossroads, roundabouts, T-junctions and pedestrian crossing aids, that risk can be mitigated by a higher lighting level.

Clearly, as long as traffic streams straight ahead without interference, the risks are limited. But where traffic streams intersect one another or overlap, the situation becomes critical, especially if different road users are involved. So, for hazard zones like that and the lighting installed for them, the standard defines the term “conflict area”. It denotes an area where special visual attention is required. Examples of conflict areas on the roads are crossroads and T-junctions, roundabouts, lay-bys for buses, toll stations, roadworks and the pedestrian crossing aids and pedestrian crossings covered in detail on pages 32-33. Another criterion identifying conflict areas is that they are typically used by motorised traffic travelling at speeds over 30 km/h, so an additional risk is presented by the need for faster response times and the difference in velocity between motorised and non-motorised traffic. That risk can be countered by optimised lighting.

More light mitigates risk in conflict areas

Lighting raised to an appropriate level is a basic requirement for a conflict area. Because no single observer position can be defined to determine luminance, the yardsticks used for assessment are average horizontal illuminance and uniformity. At the same time, care must be taken to ensure that more light does not mean more glare. The luminaires used need to be designed for good visual comfort.

45

The standard sets out a step-by-step selection procedure based on the area with the highest lighting class requirements. It starts with the lighting level of the approach road with the highest lighting class. The step-up between adjacent areas must be no more than two lighting classes. It is also advisable to create adaptation zones before and after the conflict area – especially where traffic travels at 50 km/h or more – to bridge the gap between brightness levels and enable the eye to adapt.

Roundabouts a special case

In comparison to crossroads, which are a typical conflict area (see grey box below), roundabouts are a generally safer type of junction. Hence the veritable boom in their construction in recent years. But roundabouts are still classed as conflict areas and have special lighting requirements. To ensure visual guidance, lighting needs to be from the outside of the roundabout, not from the central island. A multiple luminaire arrangement mounted on a tall column on the island, for instance, is recommended only in exceptional cases, such as very large and complex gyratory systems.

[45] Roundabouts are considered relatively safe but they are still classed as conflict areas, for which adequate EN13201 compliant lighting is required.

[47] In city centres, widely differing road users come together in a confined space. Good lighting can direct road users' eyes and reduce the risk of accidents.

46

Assessment criteria

Typical conflict areas of downtown road systems [46] include crossroads, T-junctions, roundabouts and pedestrian crossings. The assessment criteria for conflict areas are regulated by EN 13201 and depend on lighting situation, velocity, type of road users, etc. Tables in the standard are used to establish the maintained values required. Below are a few examples of parameters:

- Intersection density: The more closely spaced intersections there are, the better they need to be illuminated.
- Roundabouts need to be illuminated if the approach roads are illuminated.
- Footpaths and cycle paths at roundabouts also need to be adequately illuminated. Guidelines for pedestrian crossings on approach roads are provided in Germany by the R-FGÜ 2001 and DIN 67523.
- Marked differences in lighting level should be avoided.

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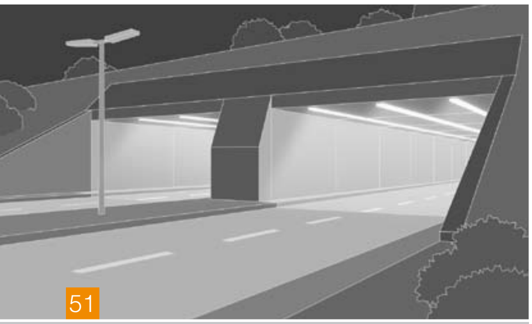
Bridge lighting

As axial transport links [50] and prominent landmarks, bridges play an important role in the urban and rural environment. Accordingly, bridge lighting needs to meet high requirements, as defined in the street lighting standard DIN EN 13201. In an urban setting, space use under a bridge also influences the lighting design, because if other transport routes are present, they need to be screened from dazzling light. Modern LED lighting technology and appropriate mounting heights guarantee effective optical control and prevent problems with glare. Accessibility on bridges is also naturally a problem that the lighting solution needs to address. LED luminaires, with long maintenance intervals, are therefore particularly suitable. As a functional alternative to column luminaires, catenary wire luminaires with asymmetrical light distribution are affixed to bridge arches or steelwork.

Tunnel lighting

For many road users, driving through tunnels is an unnerving experience – and not without reason, as serious accidents repeatedly show. Correct lighting plays a major role in making for safety here: the road ahead and any obstacles on it are recognised well in advance, adequate brightness counters the sense of confinement.



51

Assessment criteria

Road tunnel lighting [51] is regulated by German standard DIN 67 524 Parts 1 and 2. It is supplemented by international recommendations from the CIE. There are currently no uniform guidelines for Europe as a whole because a consensus has not yet been reached by the EU member states. As a result, each member state is responsible for its own national standard. The lighting assessment criterion for tunnels with vehicle traffic is luminance. It needs to be highest at the tunnel entrance so that the mouth of the tunnel does not appear as a black hole and the human eye has time to adapt to the darkness. After that, the brightness can gradually be lowered towards the tunnel interior. The values required also depend on the maximum permissible speed and the density of traffic.

It goes without saying that the lighting requirements that need to be met in tunnels and underpasses are high. Lighting solutions that take account of both technical aspects and the special psychological situation for the user promote road safety and help keep traffic flowing smoothly. This is particularly important in tunnels because restricted access means that accidents inside them present a greater risk to life and health.

Gradual transitions for the eye

Support for the adaptive capacity of the eye is a high priority in lighting design: Graduated lighting levels ease the abrupt transition from daylight to the dark interior of a tunnel and enable the motorist approaching the tunnel entrance to see inside the tunnel and identify any obstacles. The lighting solution normally adopted is an arrangement of asymmetrical luminaires positioned to provide very high illuminance at the tunnel entrance without dazzling the motorist. Then the lighting level is gradually lowered to that of the tunnel interior lighting. This should be higher than the level of normal outdoor road lighting in order to counter any sense of claustrophobia. To make for a safer transition to the brightness outside, especially during the day, it is also advisable to raise the lighting level at the end of the tunnel.

LED technology was used in tunnel lighting at an early stage – in kerbsidemarker lights installed to help motorists recognise the course of the road ahead. Today, linear LED luminaires are also increasingly used in place of the high pressure sodium vapour lamps traditionally favoured for thoroughfare lighting. Here, they play out advantages such as failsafe design, energy efficiency, precise light distribution control and good colour rendering. LED luminaires also lend themselves better to electronic switching and dimming, which facilitates the realisation of different day and night scenarios.

Conditions are harsh inside tunnels

Because of exhaust fumes and particulates, harsh conditions reign in road tunnels – and they reign 24/7 in tunnels that are in constant use. Maintenance work – whether scheduled or unscheduled – generally leads to traffic disruptions. So, selecting robust, low-maintenance luminaires is as important as correct detailed design. Lines of lights should always be mounted to one side of the central axis of the tunnel so that only one lane is blocked when maintenance work is carried out.

Light gives a sense of safety underground

In underpasses and pedestrian tunnels, the emphasis is on the subjective sense of security of passers-by. Here, particular attention should be paid to adequate semi-cylindrical illuminance so that other persons can be recognised and assessed more easily.

[48] During the day, the lighting level at a tunnel entrance needs to be particularly high so that motorists' eyes have time to adapt to the darker environment.

[49] LED marker lights make for more reliable recognition of the course of the road. A higher lighting level at the end of the tunnel helps the eye adapt to the daylight.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Street lighting and safety

Well lit streets, paths and squares help make for road safety and also help prevent crime. We know this not just from personal experience but also from a whole range of studies. The weakest road users – pedestrians, cyclists, senior citizens – are the ones who benefit the most.

Accidents: the risk increases at night

What extensive studies by the International Commission on Illumination (CIE)showed back in 1993 is corroborated by current research findings, such as those of the Dutch Institute for Road Safety Research SWOV: although there is less traffic at night, accident risk is higher and the accidents that occur are more serious. Accidents at night, for example, claim nearly twice as many lives per journey as during the day.

According to the Federal Highway Research Agency, night-time accident figures in Germany have improved over the last ten years. Accidents involving personal injury have fallen by around 20 percent and accidents involving serious injury and fatalities are around 40 percent down. For the most part, however, this is probably due to better vehicle safety features such as ABS, airbags and ESC. All the more important, then, that lighting should also play its part in lowering accident risk.

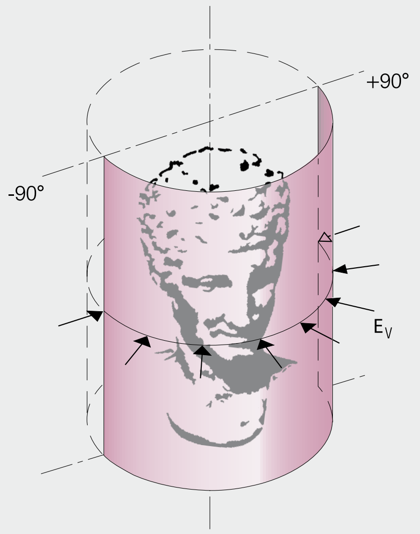
Visual performance is key

There are naturally other factors involved in the accident rate at night – fatigue or alcohol abuse, for example. Nevertheless, loss of visual acuity in darkness remains the main cause of accidents. At night, it is harder to gauge distances, colour perception is reduced and visual performance is impaired by glare. The answer is to upgrade road lighting, especially at danger spots such as intersections and pedestrian crossings.

Studies show positive effects

Not only the risks on the roads at night but also the positive effects of lighting have been amply researched. Building on another 1993 study by the CIE – which found that good lighting resulted in a 30 percent reduction in accidents on average and a 45 percent reduction on secondary roads, dangerous road sections and intersections – a Dutch meta-analysis (Elvik et al.) looked at before-and-after figures for unlit and lit roads in 2009 and found that fatal accidents fell by no less than 60 percent! Similar findings emerged from a 1994 study conducted in six German cities for the Federal Ministry of Transport. There, the total number of accidents decreased by 28 percent. Better street lighting benefits weaker road users, in particular.

Semi-cylindrical illuminance



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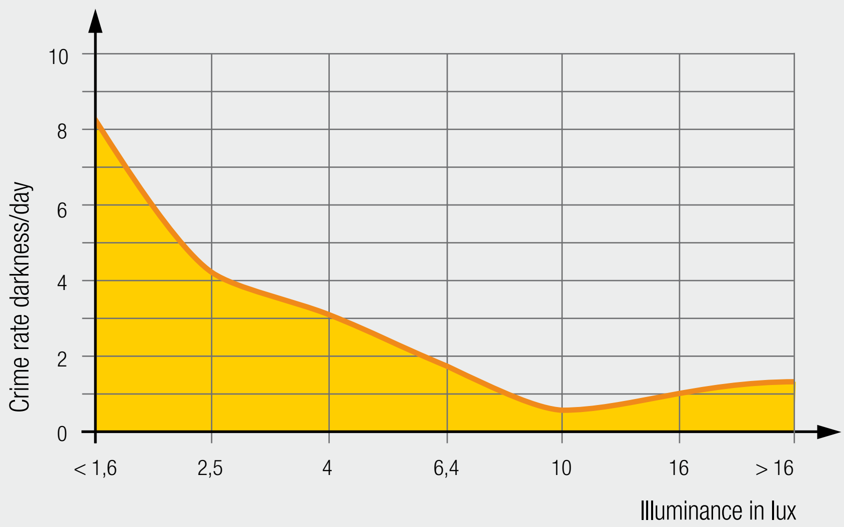
Dependence of crime rate on lighting level



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In the cases studied, accidents involving pedestrians and cyclists fell by an astonishing 68 percent.

Switching to LED yields more benefit than switching off

So, lighting has been shown to increase road safety. Even so, one in two street lights and around three quarters of traffic lights across Germany are still deactivated at 10 p.m. to save energy and cut costs.

The practice of switching off every second street light is also still common, resulting in contrasts and dark patches that overstretch the adaptive capacity of the eye. More sustainable success in reducing energy consumption and operating costs is likely to be achieved by switching obsolete lighting installations to modern LED technology. In contrast to conventional luminaires with discharge lamps, dimming systems can then be integrated to regulate the lighting installation flexibly as required. Studies also show that the distribution, brilliance and spectral composition of LED light make a positive subjective impression: road users feel safer.

Criminals fear light

Even though the effect of lighting on crime rates is not as well researched as its impacts on road safety, the studies that exist allow two conclusions to be drawn: good lighting for roads, paths and squares not only deters criminals; it also gives users of public space a greater subjective sense of security – an important goal in the drive for higher residential quality and quality of life. It is apparent that crimes like burglary, mugging and theft are more commonly committed in dark, secluded places, where perpetrators reckon they have a better chance of not being identified. By the same token, people who move around in darkness are easier prey for shady characters.

Higher illuminance generally is not the only key to good visual perception, especially for pedestrians. Good semi cylindrical illuminance – i.e. high vertical illuminance - plays a particularly important role. It enables us to recognise persons and their intentions from a distance and to react accordingly.

If better lighting results in a subjective sense of security that allows women and older people, for example, to venture out more often at night, that in itself is an achievement – because surely nothing is as effective against crime as intact social life in public space.

[52] Pedestrian underpasses are often approached with apprehension. As in this example, lighting installations can harness coloured light and high illuminance to create a more agreeable and safer environment.

[53] Semi-cylindrical illuminance is the crucial factor for facial recognition, even from a greater distance. Light from the front illuminates faces and enables features and expressions to be made out.

[54] As numerous studies have shown time and again: where illuminance rises, crime rates fall.

Energy efficiency and costs

For municipal authorities, the provision of lighting for roads, paths and squares is normally not optional; it is part of their duty to ensure safe roads. The costs need to be contained within tight local authority budgets but thanks to advances in energy efficiency, modern lighting technology is a financially attractive option.

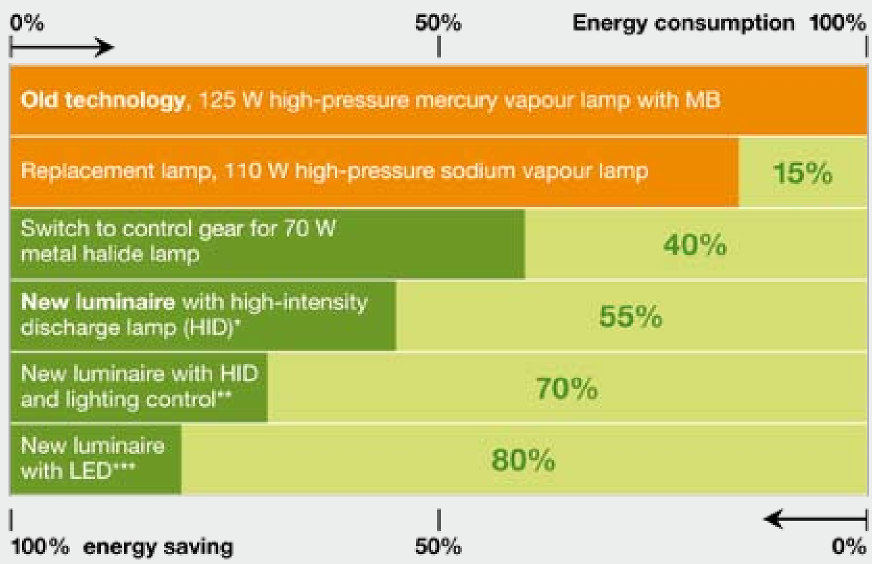
The dictates of the time have placed street lighting squarely on the agenda for local government policy makers. On the one hand, municipalities see a massive investment backlog; every second local authority taking part in a survey by the German Energy Agency DENA rated its lighting as being in need of modernisation or even badly in need of modernisation. On the other hand, LED technology today offers practical refurbishment solutions that produce not just gradual but marked improvements in energy efficiency. All street lighting investment decisions need to be based on a detailed review of costs including all the factors influencing them in the long term – because street lighting is a long-term asset. As a general rule, installations have an anticipated life of around 25 years.

Energy consumption the predominant cost factor

The total cost of street lighting is made up of capital costs, financing costs and operating costs. Capital costs are the costs of buying and installing the lighting systems and their components. Operating costs comprise costs for energy, maintenance/servicing and lamp replacement. Life cycle cost analysis, which is explained in more detail below, shows that the biggest cost element by far is the cost of energy. So that is where the biggest difference can be made in a drive to reduce lighting cost in the long run – a powerful argument for the use of innovative energy-efficient lighting technology.

Lowering costs by dispensing with lighting or by deactivating lights for certain periods of time is not a real option because local authorities have a duty to ensure safe roads– enshrined in Germany in Section 823 of the Civil Code – which includes

Savings potential in exterior lighting



* High-pressure sodium vapour lamp or metal halide lamp
** High-pressure sodium vapour lamp or metal halide lamp, with control system and 50% output for 2,000 hrs
*** With control system and 50% output for 2,000 hrs

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[55] Modern LED street luminaires save electricity, lower operating costs and provide light where it is needed – in the street – without any scattering loss.

[56] Combined with light regulation, modern lighting installations permit up to 80% savings in exterior lighting.

[57] With obsolete luminaire technology, energy consumption is the biggest cost factor in exterior lighting.

[58] A whole range of costs are incurred over the life cycle of a street luminaire. The most important ones are listed here.

a duty to provide lighting. However, liability risks of that kind are not easy to factor into the cost calculation. Nor is the economic cost of road accidents, which runs to billions. With better street lighting, that cost could at least be reduced.

Refurbishment makes sense – for the environment and for budgets

There are lots of arguments for refurbishing obsolete street lighting. They may be financial, prompted by the high failure rate of old luminaires or by problems in sourcing lamps that are no longer manufactured.

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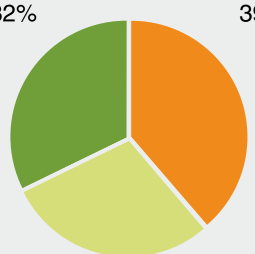
Possible cost breakdown in street lighting



The biggest cost factor in street lighting is energy consumption. With obsolete luminaire technology, energy costs can account for significantly more than the percentage shown above.

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Life cycle costs of a street luminaire
From acquisition to disposal

Life cycle costs (TCO = Total Cost of Ownership) are incurred over a defined period (e.g. 20 years) and include all costs from initial outlay through operation (incl. energy) to disposal

Capital costs
- Cost of the lighting installation
- Installation costs

Operating costs
- Energy costs
- Maintenance costs
- Cost of spare parts
- Ordering costs
- Storage costs

End-of-life costs
- Disposal costs
- Dismantling costs

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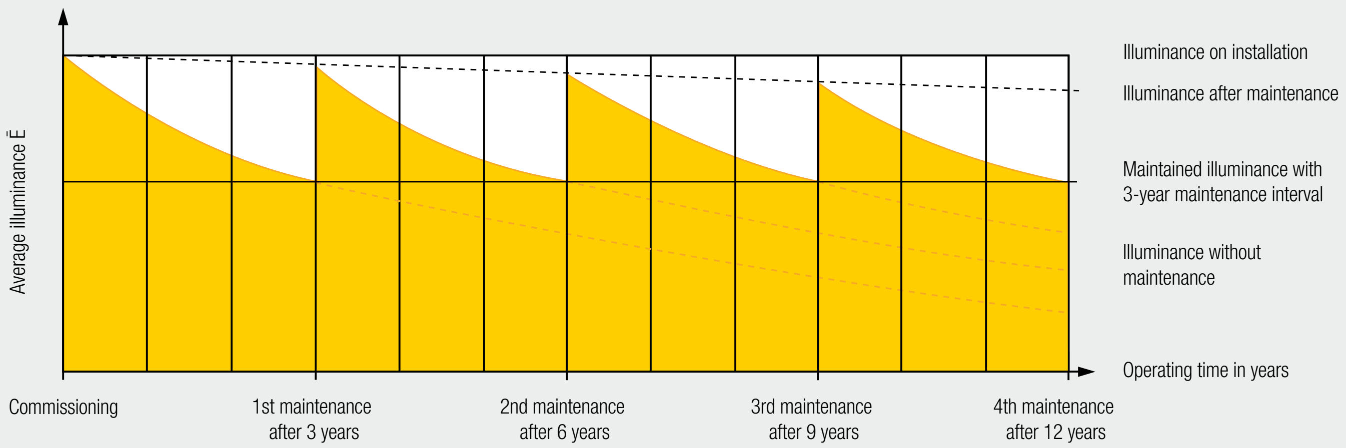
Comparison of maintenance examples

Lighting installations with low-quality luminaires



Low-quality luminaires

- Maintenance every 3 years
- Greater susceptibility to failure
- Higher costs due to more frequent maintenance

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They may be environmental, rooted in a commitment to climate targets. Or they may be promotional, aiming at making a town or city more attractive at night. In view of budgetary constraints, however, many local authorities are focused on lowering lighting costs in the medium term to ease the pressure on budgets. Life cycle cost and net present value analysis shows that thanks to the huge technological advances made in lighting, the two aims of economic efficiency and resource conservation can be perfectly combined. They thus play a central role in the refurbishment process, which is described in detail on the following pages.

Energy efficiency factors

Designers and operators have a whole range of options for improving the energy efficiency of street lighting. Opting for modern luminaires with LED light sources is certainly the most obvious one. But the effect of that decision can be enhanced by the addition of intelligent lighting management, which makes it possible for lights to be dimmed late at night, for example after midnight. Careful lighting design is also important, because only an installation that optimally meets the specific requirements of the lighting situation in question fulfils the criterion of economic efficiency.

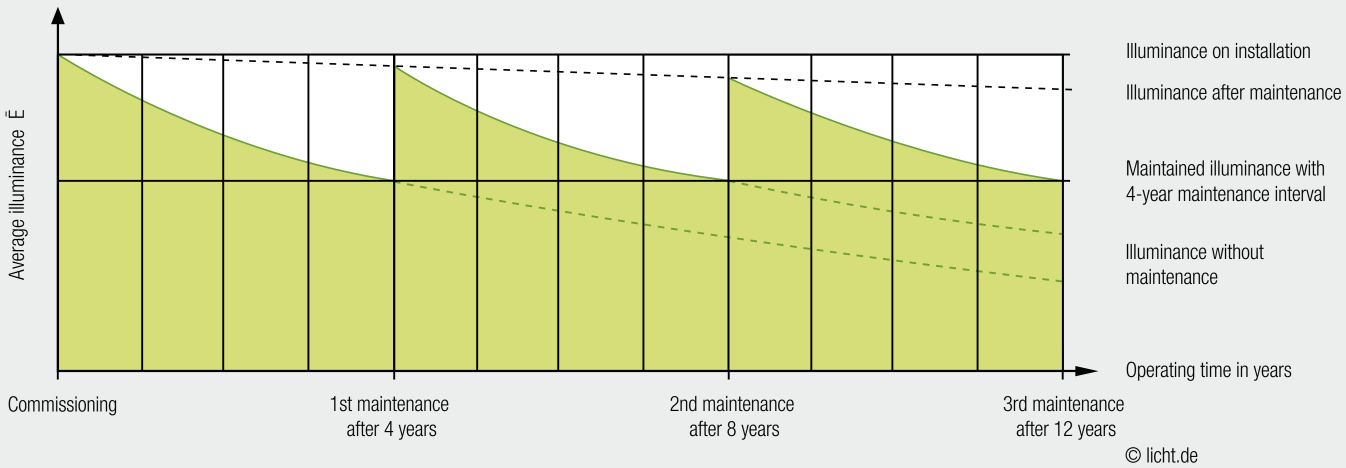
Local authorities awarding public contracts are obliged to decide in favour of the most cost-effective bid, i.e. they need to consider more than just price. An assessment matrix is a simple, practical and flexible tool for including selection criteria and lighting stipulations in an invitation to tender. The authority can thus be sure that the lighting installation offered meets the planning and other requirements that ensure that optimal energy efficiency and lighting quality are delivered throughout the life cycle of the installation.

The lessons of life cycle analysis

Street lighting life cycles are long. An operating time of 25 years is a ball park figure that is often – and even significantly – exceeded. That longevity is a good reason for not focusing cost and expense analysis exclusively on the point of investment. The entire operating life of the asset needs to be considered.

Any review of the life cycle costs of a lighting installation needs to take account of a number of factors – especially the price of electricity – in the future. And there is absolutely no reason to assume that there will be significant falls in energy prices in the coming years. The observation period selected naturally needs to be applied equally to all the alternatives considered. So do approximate values for the labour costs incurred for maintenance and servicing.

Relevant cost elements include maintenance, energy, repair, interest and ac-



High-quality luminaires
- Maintenance every 4 years
- "Maintenance with documentation" permits a longer maintenance interval up to 6 years
- Fewer failures

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quisition costs as well as disposal costs. Luminaire manufacturers need to state a failure rate for their products. The corresponding cost of replacement over the observation period also needs to be taken into account.

One crucial insight provided by the life cycle analysis of long-life assets such as street lighting is that installations requiring a higher initial outlay – and thus generally with a longer payback time – can still save more costs in the long term than installations that are amortised faster. So payback time, which is often longer for new technologies like LED than for conventional alternatives, should not be the ultimate decider: in many cases, a variant that costs more to buy – e.g. an installation with high-quality new LED luminaires – has the lowest life cycle costs.

For the experts: net present value

A method widely used in business management to assess the profitability of an investment can also be applied to street lighting – especially where operators are private companies acting under municipal supervision or contracting agreements. The method is known as net present value analysis and it takes particular account of the kind of long term savings presented by innovative LED solutions – because it applies an imputed rate of interest to the earnings resulting from energy savings. The interest is equivalent to the yield that could be obtained from an alternative investment (for example in the stock market). Net present value ultimately expresses the anticipated increase or decrease in the value of a financial asset assuming a given rate of interest over a given period of time. In the case of LED luminaires, the net present value is positive even for periods less than 10 years, which is a comparatively short time for an asset with an operating life of 25 years. Major factors shaping this result are the potential savings in comparison to the old installation as well as the price of electricity and the assumed annual rise in electricity prices. Net present value thus provides a new basis for the debate on the cost-effectiveness of refurbishment.

Availing of incentives

One last positive cost factor that local authorities should not underestimate are incentives offered for certain types of investment, for example under federal government or EU programmes. Intensive consultation with experts at the Germany Energy Agency DENA or the funding banks or energy agencies of the federal states is recommended.

[59, 60] Two different maintenance examples compared. Fig. 59 shows a 3-year maintenance interval after commissioning, Fig. 60 a 4-year interval. These examples show that selecting high-quality luminaires makes financial sense.

The refurbishment process

Once the question why street lighting should be refurbished has been answered, the question how needs to be addressed. Time-honoured tools and methods from best practice examples pave the way for successful refurbishment projects.

On the previous pages, many reasons have been given for refurbishing street lighting. Apart from the central issue of cost, they relate largely to the better quality of light delivered by modern installations, the added safety resulting from it and the reduction of carbon emissions and light pollution. Local government decision-makers are not alone in this situation. Refurbishment projects are the order of the day all over Germany. Many have already been successfully concluded and both public and private consultancy organisations stand ready to support more. Projects typically unfold in the following stages.

Project launch

It all starts with the development of political will and the involvement of lots of municipal actors. The aim is to win the support of both administrative bodies and policy-makers for the refurbishment project. Informationmedia like this booklet supply important arguments. The next step is the formation of a project team. It bundles the diverse competencies that are crucial to the success of the project through the different phases – from financing and planning to procurement and implementation. If assignments are clearly distributed and everyone involved is convinced of the need for the forthcoming measures, the project can proceed to the next phase.

As-is analysis

In the next phase, a detailed analysis of the existing lighting installation is performed as a basis for further planning. Savings potential becomes apparent here and a structured approach can be developed. Creating a "lighting register" of this kind is time-consuming but it provides the underlying data for prioritising measures on the basis of economic aspects. Services tasked with maintaining and operating the lighting – public utilities, for example – should be involved in developing the register because they often already have data on electricity consumption and costs. The data gathering itself should be

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[61] Apart from improving energy efficiency and driving down costs, refurbishment is also an opportunity to modernise the urban landscape.

[62] Example of an assessment matrix (certain columns omitted) with the key cost criteria needed to compare six different bids from six bidders and identify the option that is the most cost-effective in the long term.

Assessment matrix for streetlighting systems													
Main criteria A criteria	Weighting max. score	Bidder 1		Bidder 2		Bidder 3		Bidder 4		Bidder 5		Bidder 6	
Name		Meier		Müller		Schulze		Topp		Schneider		Schmidt	
Product		Bid 1		Bid 2		Bid 3		Bid 4		Bid 5		Bid 6	
			Punkte		Punkte		Punkte		Punkte		Punkte		Punkte
Price	30	100.00 €		150.00 €	20.00	200.00 €	15.00	250.00 €		300.00 €		350.00 €	
lowest value = 100%		100%	30.00	67%		50%		40%	12.00	33%	10.00	29%	8.60
Energy consumption in kWh/year or Energy consumption in kWh/(km x year) (use the same assessment basis for all bidders)	30	345.00 kWh		300.00 kWh	10.00	250.00 kWh	12.00	200.00 kWh		150,00 kWh		100,00 kWh	
lowest value = 100%		29%	8.70	33%		40%		50%	15.00	67%	20.00	100%	30.00
Product quality and lighting characteristics	30	29%	8.57	43%	12.86	54%	16.07	79%	23.57	43%	12.86	100%	30.00
		[illegible]	0.00	[illegible]	2.14	[illegible]	3.21	[illegible]	4.29	[illegible]	0.00	[illegible]	4.29
		38%		38%		50%		75%		63%		100%	
		[illegible]	0.00	[illegible]	2.14	[illegible]	0.00	[illegible]	4.29	[illegible]	2.14	[illegible]	4.29
		[illegible]	4.29	[illegible]	2.14	[illegible]	4.29	[illegible]	2.14	[illegible]	4.29	[illegible]	4.29
		[illegible]	2.14	[illegible]	2.14	[illegible]	0.00	[illegible]	2.14	[illegible]	0.00	[illegible]	4.29
		[illegible]	0.00	[illegible]	0.00	[illegible]	4.29	[illegible]	4.29	[illegible]	4.29	[illegible]	4.29
		25%		50%		50%		75%		25%		100%	
		[illegible]	2.14	[illegible]	2.14	[illegible]	0.00	[illegible]	4.29	[illegible]	0.00	[illegible]	4.29
		[illegible]	0.00	[illegible]	2.14	[illegible]	4.29	[illegible]	2.14	[illegible]	2.14	[illegible]	4.29
Aesthetic quality	10	50%		100%		100%		0%		100%		50%	
		average acceptance	5.00	high acceptance	10.00	high acceptance	10.00	low acceptance	0.00	high acceptance	10,00	average acceptance	5.00
Score	100		52.27		52.86		53.07		50.57		52.86		73.60
62 Rank			5		4		2		6		3		1

performed by a specialist team. Alternatively, specialised service providers may be contracted. A complete lighting register contains a record of not only the number of luminaires installed but also the nature, condition and technical details of each one. Illuminance measurements should be carried out to ascertain how well the lighting meets current service requirements and the relevant standards. Random connected load checks should also be performed to establish actual power consumption, which, in the case of old installations, is generally significantly higher than indicated by power ratings.

Planning and financing

The first step in planning is to define targets: refurbishment targets should be geared to clear objectives such as saving energy or improving lighting quality, they should be measurable and quantifiable and they should be realistic, specific and realisable within a specified time-frame. On this basis, and with professional planners and designers, a concrete action plan can be developed. To ensure that the measures projected present no procurement problems later, procurement-relevant criteria – product quality, technology and cost-effectiveness –should be defined at this stage. Project financing is also on the agenda at this point, if it has not already been dealt with. DENA surveys have shown that unsettled financing is the most common cause of failure in refurbishment projects – despite the fact that there are many different types of financing and incentive schemes available. On the previous pages, it has already been explained how life-cycle cost analysis can help ease possible pressure on municipal budgets. KfW loans or other incentive scheme funding can give municipalities more room for manoeuvre. Another option is contracting, where a private-sector supplier finances the refurbishment and then operates the installation for a contractually agreed period. The municipality has no capital costs of its own but the operator charges a contracting fee over the term of the contract to recoup its investment and make a profit.

Procurement and implementation

The municipal procurement process in Germany takes place in a strict regulatory environment (VGV, VOL, VOB). Crucially important is consideration of energy efficiency and product quality. Life-cycle cost and yield analysis also helps identify the most cost-effective option in the long run.

Assessment matrix

A tried-and-tested tool here is an assessment matrix in the form of a spreadsheet that makes it possible to compare a number of bidders on the basis of freely selectable criteria and to identify the bidder with the most cost-effective offer. By including quality features and adjusting criteria and weighting, the project team can tailor the assessment matrix to the specific acquisition. The implementation of the street lighting, i.e. the actual installation, is generally performed by specialised service providers. When inspecting the finished installation for approval, the municipality needs to verify that the services that were agreed have indeed been rendered. To ensure a long-term supply of spare parts and good service, it is always advisable to choose established manufacturers with good references.

www A version of the LED assessment matrix in German is available on the Internet at www.ptj.de/klimaschutzinitiative-kommunen/projektlaufzeit.

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Model refurbishment projects

He who hesitates now wastes money. Examples of successful street lighting refurbishment projects all over Germany show that thanks to technological advances and targeted public incentive schemes, now is the right time to act.

[63-65] Best practice in Königsfeld im Schwarzwald. After refurbishment, lighting quality rose and energy costs were reduced.

[66-68] Best practice in Bielefeld.The difference between the two photographs is particularly striking if one compares the bright facades and comparatively dark road before refurbishment with the bright road and reduced scattered light on walls afterwards.

Best Practice: Königsfeld im Schwarzwald, networked for successful refurbishment

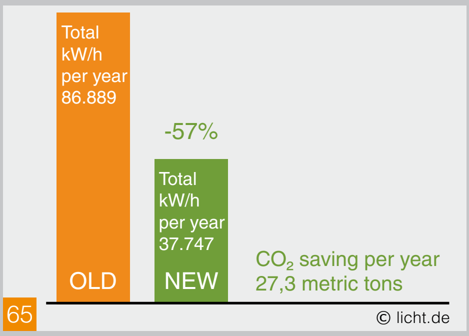
As a member of the Black Forest LED network (LED-Netzwerk Schwarzwald), the spa town of Königsfeld was among the award winners in the municipal lighting competition "Kommunen in neuem Licht" initiated in 2010 by the Federal Ministry of Education and Research (BMBF). Using the support funding to switch the obsolete town lighting to energy-efficient LED technology, the project team focused on developing LED-based lighting concepts for typical street and square situations that could also be used in other municipalities. The project was undertaken in cooperation with manufacturers in the region as well as scientists at Furtwangen University (HFU) and Technische Universität Darmstadt.

New luminaires tailored to the relevant environment

The municipality decided on neutral white LEDs for residential and commercial areas and cold white LEDs for arterial roads. The Rathausplatz square in the centre of town was furnished with completely new column luminaires to enable uniform light distribution with no dark patches or glare to be achieved by adjusting mounting heights and luminous intensity. In the spa gardens, the 38 old lanterns were replaced by 66 LED luminaires in a turn-of-the-20th-century design. Groups of trees and facades are accentuated by supplementary recessed ground lights, achieving a significant improvement in atmosphere and sojourn quality for visitors.

Energy consumption more than halved

As a result of the switch from conventional lamps to LED light sources, Königsfeld's annual energy needs are down from 86,889 kWh at 37,747 kWh. That is a 56.6 percent reduction – and saves 27.3 metric tons of CO2a year.



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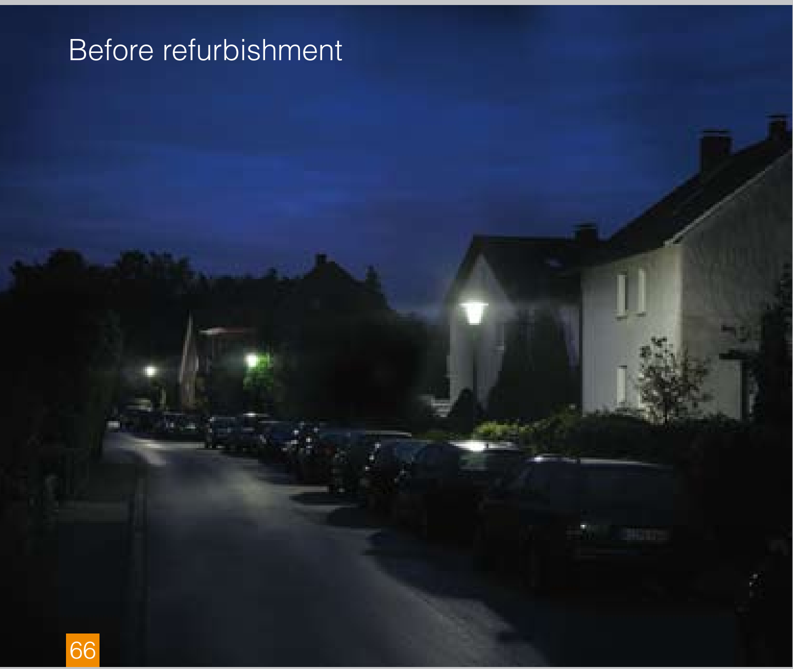
Evaluation by citizen survey

Parallel to lighting measurements, Furtwangen University conducted citizen surveys. In them, 69 percent of respond-



66 Before refurbishment

67 After refurbishment

ents said they were happy with the new LED lighting and thought they delivered optimal brightness. Over 75 percent of respondents think the new lighting is right for the situation: that is nearly 38 percent more than said the same about the old installation. The significantly better lighting level also helps create a sense of security: 70 percent of respondents said they had a very great sense of security when they were on the roads at night. In comparison to the old installation, that is a 42 percent increase.

Best practice: Bielefeld, lower energy costs – higher lighting quality

The city of Bielefeld reduced the amount of electricity consumed by public street lighting by 3.8 million kWh a year – just by replacing existing street lights with modern LED column luminaires. The large-scale switch brought the city considerable benefits in terms of energy savings, a smaller carbon footprint and better lighting quality.

Good reasons to change

In 2010, Bielefeld still had around 16,000 mercury vapour street lights in operation. The mandatory introduction of EU Regulation 245/2009 (Ecodesign Directive) banning mercury vapour lamps from being placed on the market from April 2015 onwards meant that the city was forced to act. The municipality focused from the outset on sustainable LED technology – and was able, as a result, to meet part of the capital cost of the project with financial support from the Federal Environment Ministry.

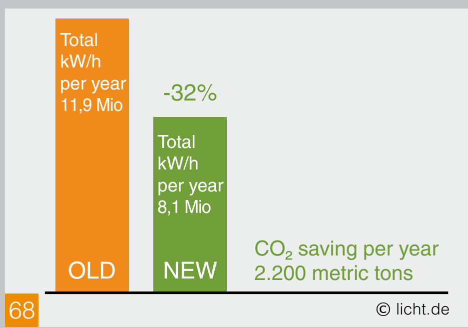
Modular LEDs for tailored lighting distribution

The LED luminaires selected have a power rating of just 21W,compared to the 89W rating of the opal glass mushroom luminaires they replace. What is more, thanks to custom-tailored optical components, they cast significantly more light where it is needed and avoid unnecessary scattering loss.

The luminaires installed now provide much brighter illumination for traffic areas in what are generally eight to ten metre wide residential and local access streets. For these lighting situations, the luminairesare fitted with special lenses for asymmetrical light distribution. Thanks to their precisely controlled beam, there are no longer any problems with light shining on bedroom or living room windows. The luminaires permit around a 50 percent power reduction between 10.30 p.m. and 4.30 a.m. Exceptionally wide footpaths behind the columns and footpaths or cycle paths set back from the road can also be illuminated well by supplementary LED bars. With columns up to 40 metres apart and five metres high and with streets up to 10 metres wide, road and path surfaces are significantly better and more evenly illuminated.

Energy savings add up

An 83 percent energy andCO2savingis achieved for every HQL luminaire replaced. With around 31,000 luminaires in Bielefeld, the replacement programmes in 2011and 2012/2013 made for an energy saving of around 32%. As a result, CO2 emissions will be reduced by 2,200 metric tons a year and energy consumption cut by 3.8 million kWh/year. What is more, the luminaires emit insect-friendly light and there is less light pollution in residential and local access streets because light is directed onto road and path areas.



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Incentive schemes

Last but not least, the best practice examples show how decision-making and refurbishment processes are facilitated for municipalities by the use of incentive funding. Important addresses for financial support for refurbishment projects are the Federal Environment Ministry and the government-owned KfW bank. More incentive schemes are in place at federal, state and European level; information about them is available, for example, from the federal and state energy agencies.

Standards, literature, useful websites

Municipal lighting is a complex subject. Standards are revised and new incentive schemes introduced, modified or discontinued. The latest information is mostly found on the Internet but specialist literature can also provide bearings for anyone lost in the street lighting jungle.

The most important standard for street lighting is DIN EN 13201. At present – at the beginning of 2014 – it is being revised. No publication date has yet been set.

DIN **13201-1** (Part 1) refers only to Germany. Parts 2 to 4 are also European standards. Part 1 describes a comprehensive system for identifying typical street and road lighting situations. These are divided into different lighting classes, which in turn define the minimum lighting values that need to be reached.

DIN EN **13201-2** defines more requirements for the different users and the values needed to meet them.

DIN EN **13201-3** stipulates how quality features should be mathematically defined and applied.

DIN EN **13201-4** defines the different methods for measuring quality features and street lighting installations.

Other standards, guidelines and publications supplementing DIN 13201:

DIN EN 12464-2
Light and lighting –Lighting of work places
Part 2: Outdoor work places

DIN 5340
Terms for physiological optics

DIN 67523
Lighting of pedestrian crossings with additional lighting
Part 1: General quality characteristics and guide values
Part 2: Calculation and measurement

[69] Luminaires with projector/reflector lighting systems provide glare-free, homogeneous lighting for pedestrian precincts and squares. The fountain lighting adds a decorative feature to the urban landscape.

R-FGÜ 2001
Richtlinien für die Anlage und Ausstattung von Fußgängerüberwegen (Guidelines for the construction and configuration of pedestrian crossings), published in Verkehrsblatt (VkBl) 2001, page 474 (www.verkehrsblatt.de)

DIN 67524
Lighting of street tunnels and underpasses
Part 1: General quality characteristics and guide values
Part 2: Calculation and measurement

CIE publication 88
Guide for lighting of road tunnels and underpasses, 2nd edition, Vienna 2004 (www.cie.co.at/cie)

RABT
Richtlinie für die Ausstattung und den Betrieb von Straßentunneln (Guidelines for the equipment and operation of road tunnels), Cologne 2006, published by Forschungsgesellschaft für Straßen- und Verkehrswesen e.V. (FGSV) as title 339 (www.fgsv-verlag.de)

Life behaviour of discharge lamps for general lighting
Fachverband Elektrische Lampen, ZVEI – Zentralverband Elektrotechnik- und Elektronikindustrie e.V., Frankfurt am Main 2005 (www.zvei.org)

Publication No. 17:1998
Straßenbeleuchtung und Sicherheit (Street lighting and safety)
Deutsche Lichttechnische Gesellschaft (LiTG) e.V., Berlin (www.litg.de)

Publication No. 12.3:2011
Messung und Beurteilung von Lichtimmissionen künstlicher Lichtquellen (Measurement and assessment of light immissions from artificial light sources)
Deutsche Lichttechnische Gesellschaft(LiTG) e.V., Berlin (www.litg.de)

Publication No. 15:1997
Einwirkung von Außenbeleuchtungsanlagen auf nachtaktiveInsekten (Impact of outdoor lighting installations on nocturnal insects) Deutsche Lichttechnische Gesellschaft (LiTG) e.V., Berlin (www.litg.de)

Hinweise zur Messung und Beurteilung von Lichtimmissionen (Guidelines on the measurement and assessment of light imissions) Länderausschuss für Immissionsschutz (LAI) resolution of 10 May 2000 (www.lai-immissionsschutz.de)

Further links and useful websites

DENA street lighting guide
http://www.lotse-strassenbeleuchtung.de/

Overview of incentive funding options – Incentive database
http://www.foerderdatenbank.de/

KFW promotion programmes
http://www.kfw.de

Tool and decision-making aid for LED luminaire selection
http://www.zvei.org/Verband/Publikationen/Seiten/Arbeits--und-Entscheidungshilfe-zur-Auswahl-von-LED-Leuchten.aspx

Assessment matrix for street lighting
www.ptj.de/klimaschutzinitiative-kommunen/projektlaufzeit

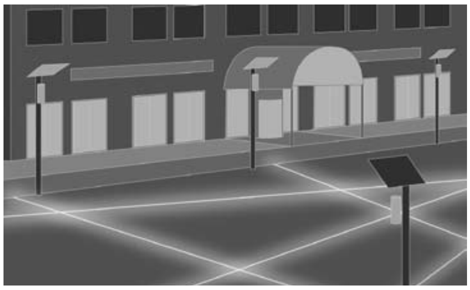
Luminaires and their applications

Modern luminaires offer myriad opportunities to design outdoor space for comfort and safety without ignoring normative illuminance requirements. Below is an overview of the most important types of luminaire, along with details of their specific product features and tips on correct use.

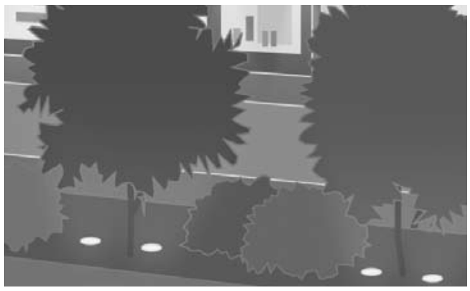
Which luminaires produce what kind of light? Which lighting technology is the right choice? And which type of luminaire should be used to ensure compliance with standards? Selecting the right luminaires is not always easy for an operator. There are innumerable stipulations and just as many design options for municipal lighting. The first question that has to be answered is: What lighting task will the required luminaire need to perform? The lighting tools required to illuminate a multi-lane highway, for instance, are very different from those needed to illuminate a facade. The types of luminaire shown on these pages give an idea of the range of functions and applications.

The key criteria for luminaire selection are generally technical ones: luminous intensity, lumens per watt, mounting height and beam angle are examples. But choosing the right lighting technology calls for a fundamental decision. LED luminaires and LED modules have revolutionised the market in recent years and have already superseded former market leaders such as metal halide lamps, high-pressure sodium vapour lamps or fluorescent lamps in many areas. Their allure resides largely in high energy efficiency and long product life.

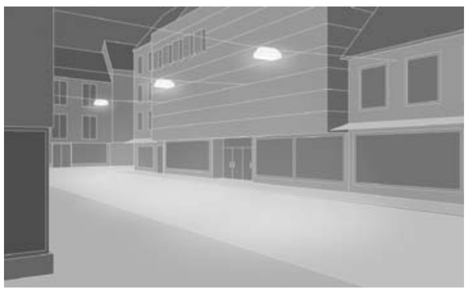
Luminaire design also plays an important role in product selection. The shape of a luminaire should suit the surrounding architecture to create a coherent picture overall. A luminaire's visual impact during the day should not be underestimated. It is an object in the public space and as such is an important part of the urban landscape.



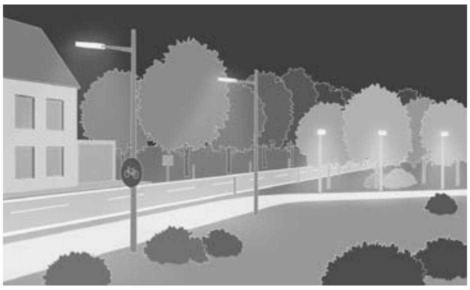
Linear recessed ground lights are popular for decorative street or square lighting. The continuous rows can also work with RGB-control and coloured light to provide special accents.



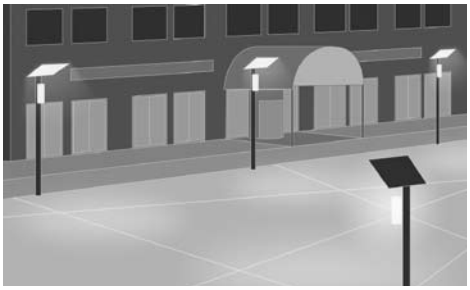
Recessed ground luminaires can illuminate trees and shrubs from below and thus accentuate them in their surroundings. However, their narrow or wide-angled glancing light can also be used to cast facades or walls in a dramatic light.



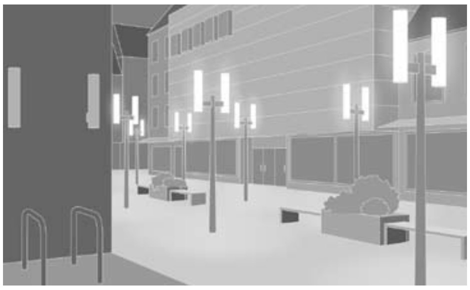
Catenary-wire luminaires are perfect problem-solvers. Suspended over the middle of streets or alleyways, they provide optimal illumination.



Side-entry column luminaires, mounted singly or in pairs, are universal, energy-efficient street lighting solutions. Two-arm models are predestined for illuminating wide streets or car parks.

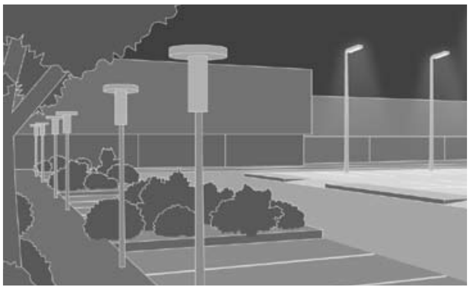


Post-top luminaires with secondary lighting technology, also known as projector/reflector systems, provide uniform, glare-free lighting by bouncing light off a reflective surface. They are an ideal choice for pedestrian precinct and square lighting.

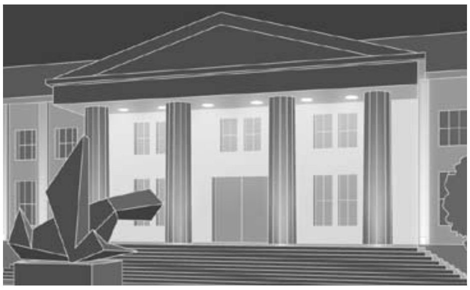


Decorative post-top luminaires provide not only functional lighting but also design highlights for squares, pedestrian precincts, parks or paths. They can be combined to good effect with wall luminaires from the same product family.

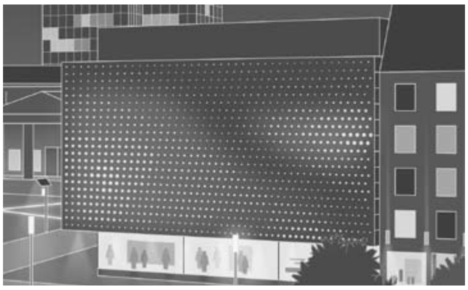
High-performance column luminaires in floodlight designs provide efficient, homogeneous illumination even over large areas such as motorway service areas, car parks, industrial sites or sports grounds.



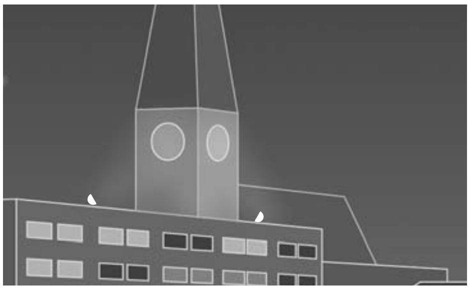
Column luminaires and light pillars are used as technical and decorative exterior luminaires for illuminating roadways, paths and squares. In some cases, functional elements such as connections for gas, electricity, water, etc. can be combined with the luminaires.



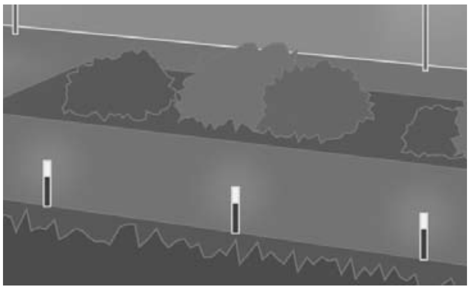
Recessed/surface-mounted ceiling luminaires provide light in arcades, under canopies or overhangs. Discreetly integrated in the architecture or conspicuously presented as a decorative luminaire, they can be used to create outdoor light spaces.



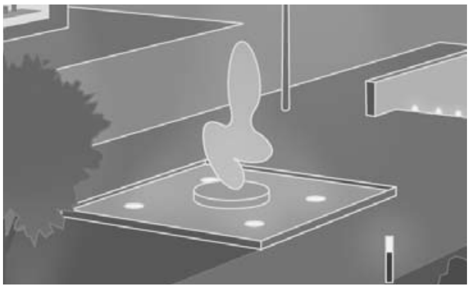
Media facades permit ever-changing presentations of still or moving images and thus become giant screens that constantly restructure facades or grab attention with advertising messages.



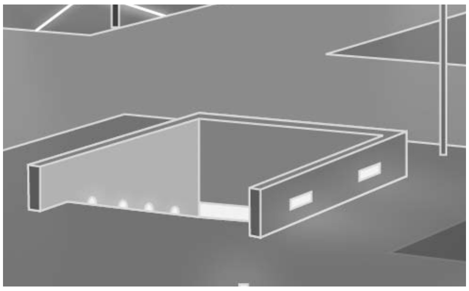
Floods and spots are used for large-area illumination of buildings, monuments or places of interest. Mounted on buildings or columns, they are also suitable for distant illumination.



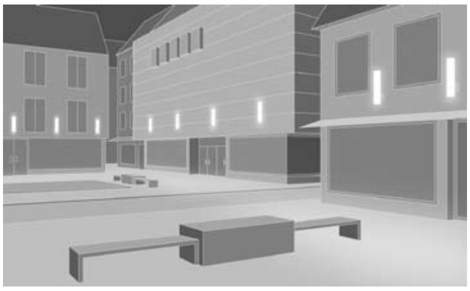
Bollard luminaires are generally used for path lighting in parks and gardens but also for zonal lighting in squares. They facilitate orientation and play a decorative role in the landscape.



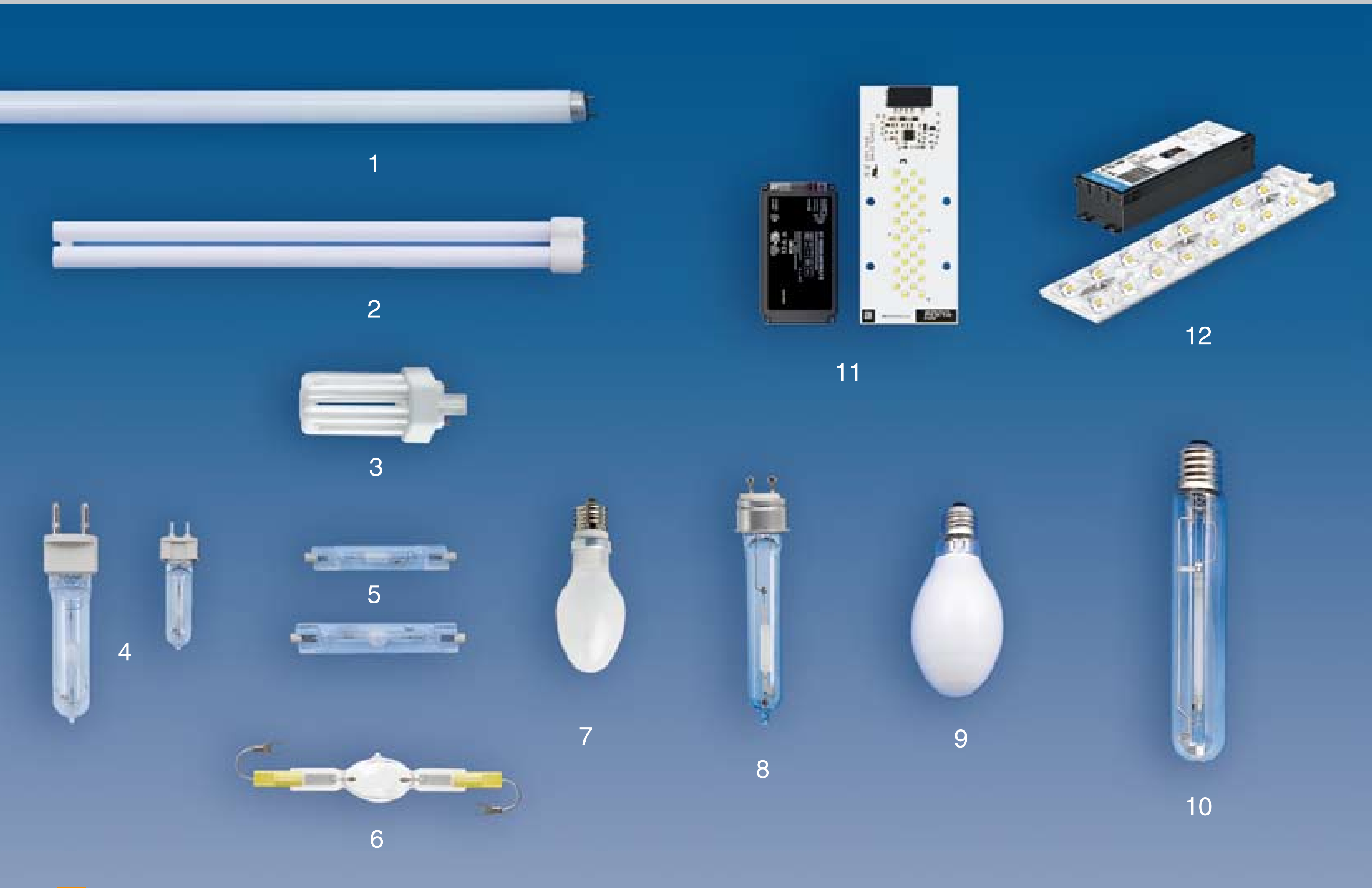
Underwater luminaires, operating with LEDs or optical fibres, offer advantages in terms of maintenance and permit dynamic lighting effects with white or coloured light.



Recessed wall luminaires facilitate orientation, e.g. on stairs or as route markers, and make for a greater sense of security.



Surface-mounted wall luminaires can be used to illuminate adjacent areas such as paths and squares or to provide special accentuating light for facades.



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Nr.	Lamptype	Power rating classes (nominal rating in Watt)	Luminous flux (Lumen)	Luminous efficacy (Lumen/Watt)	Light colour
	Linear fluorescent lamps				
1	Fluorescent lamp Ø 26 mm	18 – 70	870 – 6,200	61 – 89	ww, nw, dw
	Compact fluorescent lamps				
2	2-tube lamp, elongated	16 – 80	950 – 6,500	67 – 100	ww, nw, dw
3	1-, 2- or 3-tube lamp, compact	10 – 42	600 – 3,200	60 – 75	ww, nw, dw
	Metal halide lamps				
4	Single-ended with ceramic technology	20 – 400	1,600 – 41,000	80 – 108	ww, nw
5	Double-ended with ceramic technology	70 – 150	5,100 – 14,500	73 – 104	ww, nw
6	Double-ended	1,000 – 2,000	90,000 – 230,000	90 – 117	nw, dw
7	Ellipsoidwith ceramic technology	35 – 150	3,200 – 13,700	84 – 94	ww, nw
8	Tubular with ceramic technology	45 – 315	4,300 – 37,000	96 – 120	nw, dw
	High-pressure sodium vapour lamps				
9	Ellipsoid design	50 – 1,000	3,800 – 130,000	88 – 150	ww
10	Tubular design	35 – 1,000	2,200 – 128,000	63 – 139	ww
	LED modules				
11	LED module (manufacturer-specific and ZHAGA-compliant), without optics or heat sink	18 – 75	2,500 – 10,000	110 – 140	nw, dw
12	LED module, technical lighting (manufacturer-specific), with optics, without heat sink	15 – 45	2,100 – 5,000	111 – 139	nw, dw
13	LED module, technical lighting (manufacturer-specific), with optics and heat sink	32 – 60	2,700 – 6,000	87 – 100	ww, nw
14	LED module, technical lighting (manufacturer-specific), without optics, with heat sink	21	2,600	120	ww, nw, dw

ww = warmwhite colour temperatures up to 3,300 K nw = neutral white colour temperatures 3,300 K to 5,300 K dw = daylight white colour temperaturesover 5,300 K

13

14

Colour renderimg Index R_a (in some case as range)	Base
85 – 98	G13
80 – 93	2G11; 2G7
80 – 90	G23; G24; 2G7; GX24
80 – 85	G8,5; G12; G22 GU6,5; GU8,5; GY22
75 – 95	RX7s; RX7s-24
65 – 90	K12s
85 – 93	E27
60 – 90	PGZ12; PGZ18
25	E27; E40
25	E27; E40
>70	–
>70	–
>70	–
>80	–

Light sources

As of 13 April 2015, new high-pressure mercury vapour lamps may no longer be placed on the market in the EU. Here we show the most important current LED modules and lamp types facilitating the switch to efficient lamp technologies.

Linear fluorescent lamps and compact fluorescent lamps [1-3]
The distinctive features of linear fluorescent lamps and compact fluorescent lamps are high luminous efficacy, good colour rendering and longevity. For outdoor applications, special variants delivering uniformly high luminous flux over a temperature range from 5 °C to 70 °C should be used. The lamps can be dimmed with appropriate electronic ballasts.

Metal halide lamps [4-8]
The impressive feature of metal halide lamps is their brilliant light, which makes for an attractive urban landscape. Lamps with ceramic burner technology are extremely energy-efficient, achieving a luminous efficacy up to 100 lm/W, and are thus significantly more energy-efficient than lamps with quartz burners. Because of their good colour rendering and high-quality light, they are particularly suitable for prestige applications such as the illumination of monuments, fountains or historical buildings. Variants specially developed for street lighting have a long service life and are optimised for long replacement intervals.

High-pressure sodium vapour lamps[9-10]
High-pressure sodium vapour lamps are noted for very high luminous efficacy up to 150 lm/W and longevity. Variants for street lighting have a very low premature failure rate of just 5% at 24,000hrs. Six-year replacement intervals are thus realised. However, compromises need to be made in terms of light quality because the lamps have a colour rendering index of only $R_a \leq$ 25 and cast a yellowish light. Some variants permit a simple one-for-one switch from high-pressure mercury vapour lamps to high-pressure sodium vapour lamps.

LED modules [11-14]
LED modules are light sources that work with individual LEDs mounted on printed circuit boards (PCBs). Depending on configuration, modules may be fitted with light-controlling optics and a heat sink. Modern modules achieve very high luminous efficacy ratings. What is more, the light sources have a very long life. Luminous efficacy and longevity are dependent on the temperatures to which the LEDs are exposed in operation. Low temperatures extend life and heighten efficiency and thus enable LED modules to play out their strengths in full.

LED modules form an integral part of LED luminaires. With appropriate optics incorporated in the luminaires, scattered light and glare can be optimised for energy efficiency and lighting comfort.

An LED module always requires appropriate control gear. The control gear used should always meet the standards required for street lighting. A high degree of protection and overvoltage protection is also important. Which ballasts are suitable for use with which LED modules can be established by asking the manufacturer. Special versions come with different control interfaces (e.g. DALI or AstroDIM) or with additional functions such as luminous flux adjustment.

Available light engines (LED modules and control gear) are either manufacturer-specific or defined by e.g. Zhaga. Zhaga is an initiative developing uniform standards for light engines.

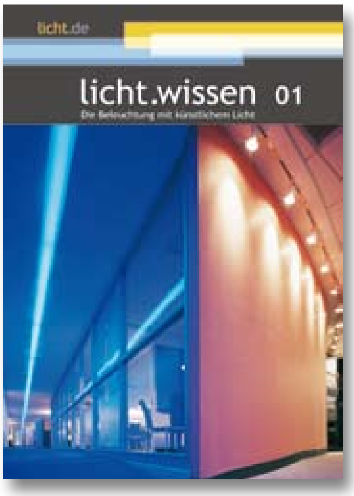
Each booklet! €10,-

The licht.de series of booklets

licht.wissen 16

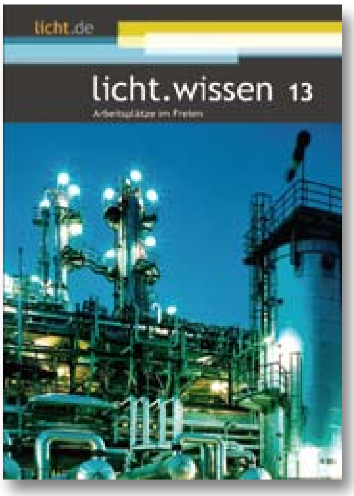
City Marketing with Light

40 pages on distinctive urban lighting. Booklet 16 explains how attractive, energy-efficient lighting design can sharpen a municipal profile. Three master plans and lots of practical examples present good city marketing solutions.

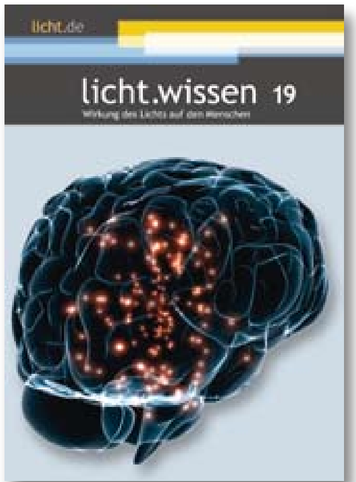


[Booklet 01] 60 pages on the basics and art of artificial lighting. Booklet 01 describes the physical components of light and conveys key information about lighting technology.

[Booklet 02] 56 pages of comprehensive information on efficient professional lighting for educational establishments. Booklet 02 also shows how good lighting can boost motivation and performance in a learning situation.



[Booklet 13] 32 pages on lighting for outdoor work operations.Booklet 13 explains what criteria need to be met by outdoor workplace lighting. It is based on the European standard DIN EN 12464 Part 2 and other norms.



[Booklet 19] 56 pages on the biological impacts of lighting. Booklet 19 reports on the current state of research and presents practical examples showing how dynamic lighting can be realised.

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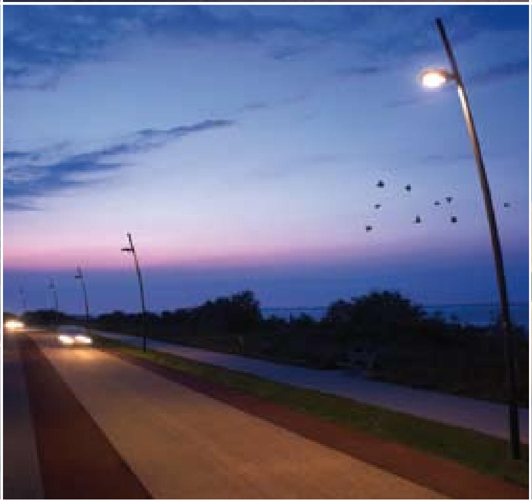

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