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Roads, Paths and Squares

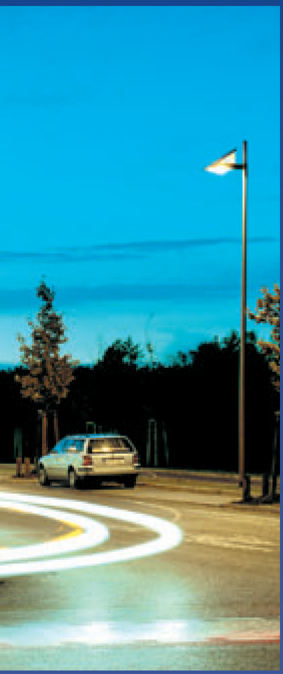
Content

In 2005, 2,143 of 5,361 roads deaths in Germany occurred on quiet roads at night; 31.6% of the road users who were seriously injured were involved in accidents at twilight or after dark.

1

Good road lighting improves visual performance and reduces accidents by an average of 30%.

As illuminance increases, the incidence of car theft, burglaries, physical and sexual assault and other forms of night crime sharply decreases.



2

With a connected load of 13W per person, the electricity consumed by road lighting works out at just 55 kWh a person a year.

Road lighting costs 17.15 euros per person a year, only 7.15 euros of which is for electricity.

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4

Seeing and being seen

Light and vision
There is a simple recipe for preventing accidents: see and be seen. But vision is a complex process. Road lighting needs to take account of that.

Daylight illuminance ranges from 5,000 to 100,000 lux (lx). On a moonlit night, it reaches 0.25 lx at most. The fact that we can “see” over this vast brightness range is due to the eye’s ability to adapt. At low adaptation levels, however, visual performance is impaired.

Cones for colour vision, rods for seeing in the dark
Visual performance is best in daylight, when the eye’s colour-sensitive cone receptors are active: colours are easily distinguished, objects and details clearly made out. In darkness, different receptors take over. These are the rods, which are fairly insensitive to colour but highly sensitive to brightness. In the transitional stage, in twilight, both receptor groups are active.

Identification depends on contrasts
Contrasts are differences in brightness and colour in the visual field. To be perceived by the human eye, they need to be sufficiently pronounced. The minimum contrast required for perception depends on the ambient brightness (adaptation luminance): the brighter the surroundings, the lower the contrast perceived. In darker surroundings, an object needs either to contrast more sharply or be larger in order to be perceived.


5

Photo 5: As darkness increases, visual performance deteriorates. Road lighting restores lost performance, enabling shapes and colours to be adequately made out.

6

Photo 6: In daylight, visual performance is at its peak: the eye's colour-sensitive cone receptors are active, every detail is perceived vividly "in colour".

The four basic lighting quantities

Luminous flux (Φ) is the rate at which light is emitted by a lamp. Measured in lumen (lm), it defines the visible light radiating from a light source in all directions.

Luminous intensity (I) is the amount of luminous flux radiating in a particular direction. It is measured in candela (cd). The spatial distribution of luminous intensity – normally depicted by an intensity distribution curve (IDC) - defines the shape of the light beam emitted by a luminaire, reflector lamp or LED.

Illuminance (E) – measured in lux (lx) – is the luminous flux from a light source falling on a given surface. Where an area of 1 square metre is uniformly illuminated by 1 lumen of luminous flux, illuminance is 1 lux. The flame of an ordinary candle, for example, produces around 1 lx at a distance of 1 m.

Luminance (L) is the brightness of a luminous or illuminated surface as perceived by the human eye. Measured in cd/m^2 or cd/cm^2, it expresses the intensity of the light emitted or reflected by a surface per unit area.

Contrast sensitivity
The ability to perceive differences in luminance in the visual field is called contrast sensitivity. The higher the brightness level (adaptation luminance), the finer the differences in luminance perceived. Contrast sensitivity is reduced by glare (see Pages 4/5).

Visual acuity
The eye's ability to make out the contours and colour details of shapes – such as a traffic obstruction – is determined by visual acuity. Visual acuity improves as adaptation luminance increases.

Visual performance
Visual performance is determined by contrast sensitivity and visual acuity. It also depends on the time in which differences in brightness, shapes, colours and details are perceived (speed of perception). A person travelling fast has much less time for this than a pedestrian.

Adaptation time
It takes time for the eye to adapt to different levels of brightness. The adaptation process – and thus the adaptation time – depend on the luminance at the beginning and end of any change in brightness: adapting from dark to light takes only seconds, adapting from light to dark can take several minutes.

Visual performance at any one time depends on the state of adaptation: the more light is available, the better the visual performance.

Visual impairment occurs when our eyes have too little time to adapt to differences in brightness. Hence the need for adaptation zones – e.g. at tunnel entrances and exits - to make for a safe transition between one luminance level and the other.

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Photo 7: Daylight: Optimum visual performance, good colour discrimination, objects and details can be clearly made out.

Photo 8: Road lighting: Shapes and colours are much harder to make out but can still be adequately distinguished.

Photo 9: Moonlight: Colour perception is not possible, low-contrast details are no longer discernible.

Adequate level of brightness
To enable us to see well, an adequate level of brightness (lighting level) is essential. Level of brightness is determined by illuminance and the reflectance properties of the illuminated surface or the luminance of luminous surfaces.

Illuminance (in lx) is the amount of light falling on a surface. Luminance (in cd/m^2) is the light reflected by the surface into the eyes of the observer. This is perceived as brightness.

Luminance
Luminance depends on the position of the observer, the geometry of the lighting installation, the intensity distribution of the luminaires, the luminous flux of the lamps and the reflective properties of the road surface. Luminance is calculated for standard assessment fields.

Photos 10 and 11: The uniformity of the luminance along and across the roadway is good (Photo 10). Switching off individual luminaires (Photo 11) severely discrupts the longitudinal uniformity of the roadway luminance.

Illuminance
For all roads or sections of road where luminance assessment is not possible because neither clear-cut assessment fields nor a standard observer position can be defined, illuminance is the yardstick used. What is assessed is the horizontal illuminance on the roadway. Where pedestrian traffic is heavy, other types of illuminance (see Fig. 2) such as vertical or semi-cylindrical illuminance are also used (see also page 15).

Value on installation
The luminance and illuminance values recommended in DIN EN 13201 are maintained values, i.e. values below which luminance or illuminance must not fall at any time. As the length of time a lighting installation is in operation increases, the values installed at the outset decrease as a result of lamps and luminaires ageing and becoming soiled. So, to enable an installation's operating life to be extended without additional maintenance work, values on installation should be correspondingly higher. How much higher is determined by maintenance factors.

Values required on installation are calculated as follows: value on installation = maintained value / maintenance factor.

Uniformity makes for safety
It is not enough just to maintain the correct lighting level. Brightness also needs to be distributed evenly so that visual tasks – including the "navigational tasks" referred to in the standard – can be properly performed. Dark patches act as camouflage, making obstacles and hazards hard to make out or completely concealing them from view. Camouflage zones occur where too few luminaires are installed or individual luminaires are deactivated or defective.

Overall uniformity of illuminance U_O is the quotient of the lowest and mean illuminance.

Uniformity of luminance is established by calculating the overall uniformity U_O and the longitudinal uniformity U_l, taking account of the geometry (assessment field) and reflectance properties of the roadway. Overall uniformity U_O is the ratio between the lowest and mean luminance values over the entire roadway; longitudinal uniformity U_l is the ratio between the lowest and highest luminance values in the centre of the observer's lane.

Limiting glare makes for better visual performance
Glare can impair visual performance to such an extent that reliable perception and identification are impossible. Physiological glare (disability glare) results in a measurable reduction of visual performance. Psychological glare (discomfort glare) is discomforting and distracting and thus also causes accidents.

Glare cannot be avoided altogether but it can be greatly limited. Standard assessment procedures exist for both kinds of glare.

Veiling luminance
Physiological glare occurs as a result of excessively high luminance in the visual field or differences in luminance to which the eye cannot adapt. The source of glare creates scattered light which spreads over the retina like a veil and substantially reduces the contrast of the images projected onto it.


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11

The higher the glare illuminance at the observer's eye and the closer the glare source, the higher the veiling luminance.

Glare assessment and threshold increments
At adaptation luminance $\bar{L}$, an object and its surroundings need at least luminance contrast L_O for the object to be identifiable. Where glare occurs, veiling luminance causes the eye to adapt to the higher luminance level $\bar{L} + L_S$: at luminance contrast ΔL_O, the visual object is invisible. To make it discernible, the luminance contrast needs to be raised to ΔL_{BL}.

This percentage rise in threshold values TI (Threshold Increment)from ΔL_O to ΔL_{BL} is the measure of physiological glare. Where the luminance calculation produces high TI values, glare is intense. Effectively glare-suppressed lighting installations have threshold increments between 7 and 10%.

Direction of light
Directional light can create shadow zones – e.g. between parked vehicles – where brightness is unevenly distributed. Where deep shadows cannot be avoided, supplementary lighting is the answer.

Light colour and colour rendering of lamps
Light colour describes the colour of the light radiated by a lamp. Colour rendering refers to the effect its light has on the appearance of coloured objects.

In outdoor lighting, these two characteristics are of relatively minor importance. Even so, it is still advisable to use lamps with good colour rendering properties so that discernible colour contrasts are perceived and information intake is thus maximized.

Lamps with poor colour rendering properties, such as low-pressure sodium vapour lamps, are only suitable for pedestrian crossing, seaport and security lighting.

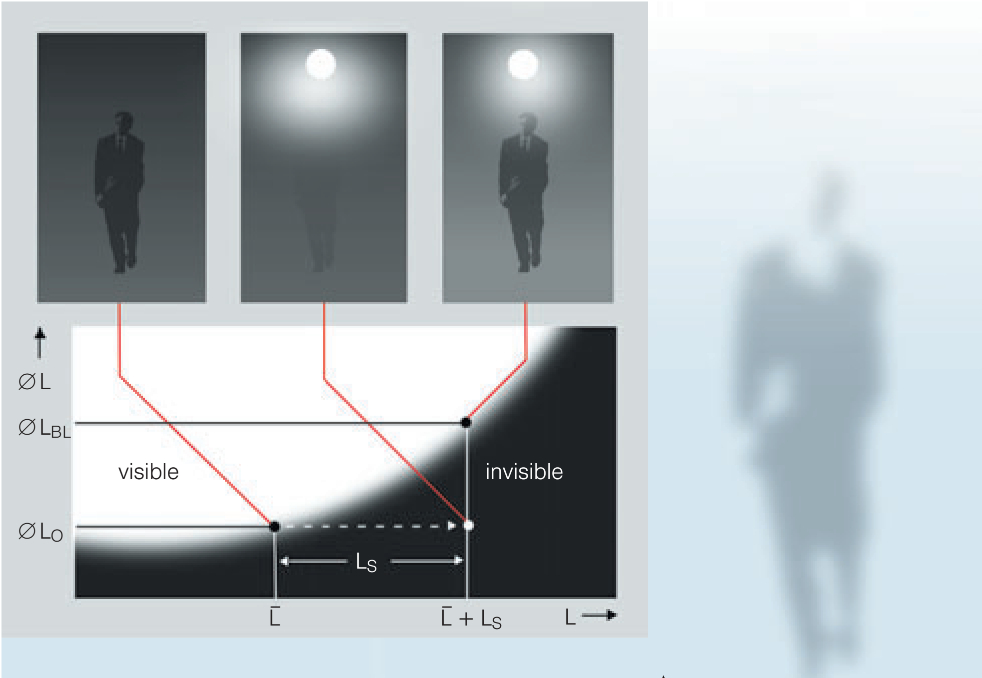
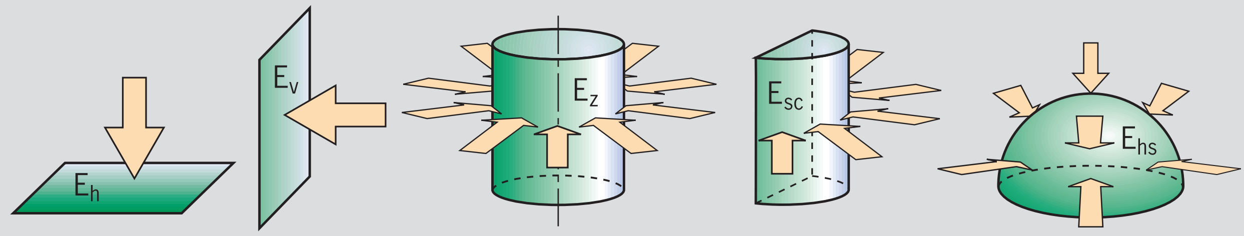


Fig. 1: Where glare occurs, luminance contrast must be raised to ΔL_{BL} in order to make the visual object discernible.

Types of illuminance (Fig. 2)



E_h = *horizontal illuminance. This is determined by the luminous flux falling on the flat horizontal surface*

E_v = *vertical illuminance. This is determined by the luminous flux falling on the flat vertical surface*

E_z = *cylindrical illuminance. This is determined by the luminous flux falling on the entire curved surface of an upright cylinder*

E_{sc} = *semi-cylindrical illuminance. This is determined by the luminous flux falling on the curved surface of an upright semicylinder*

E_{hs} = *hemispherical illuminance. This is determined by the luminous flux falling on the curved surface of a hemisphere standing on the surface being assessed.*

Vertical and semi-cylindrical illuminance are direction-dependent.

Requirements are determined by risk potential
The greater the risk of accidents at night, the more light a road lighting system needs to provide. Where traffic volumes are high, so is risk potential – and the danger of collision is even greater where road users differ in speed, size and identifiability, i.e. they include motorists, cyclists and pedestrians. Closely associated with this is the safety of the road itself, which depends on its size, its location and the speed limit that applies.

Selection procedure
DIN 13201-1 classifies situations in several stages and sets out lighting requirements – including minimum values – on the basis of this selection procedure.

Lighting situations
The lighting situations A1 to E2 (see table headed "Lighting situations according to DIN 13201") describe the key criteria for road risk:

- Main users of the traffic area
- The speed at which they travel
- Other users allowed
- Excluded users

The first step (primary parameter) of lighting planning is to classify the road in question according to the lighting situations defined.

Lighting classes
After that, an appropriate lighting class needs to be selected for the lighting situation. This is done with the help of standard and supplementary tables that take account of specific parameters. Once an appropriate lighting class has been identified, the lighting design requirements can be established (checklist: see "Lighting class planning aid (DIN 13201-1)" on page 8). The standard tables take account of e.g. the following criteria:

- Physical traffic-calming measures – these need to be reliably identified.
- Intersection density – the more intersections, the greater the collision risk.
- Difficulty of navigational task (visual task) – this may be "higher than normal" where the information presented requires a particularly high degree of effort on the part of the road user to decide how fast he should travel and what kind of manoeuvres can be safely performed on the road.
- Average daily traffic (ADT) – because more data usually come from surveys conducted in daylight, the figure used here is weighted to account for both day and night-time traffic.

Lighting situations according to DIN EN 13201

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
A1	> 60 km/h	Motorised traffic		Slow moving vehicles, cyclists, pedestrians	Motorways and roads for motor vehicles only
A2			Slow moving vehicles	Cyclists, pedestrians	Major country roads, poss. with separate cycle- and footpath
A3			Slow moving vehicles, cyclists, pedestrians		Minor country roads
B1	30–60 km/h	Motorised traffic, slow moving vehicles	Cyclists, pedestrians		Trunk roads, through roads, local distributor roads
B2		Motorised traffic, slow moving vehicles, cyclists	Pedestrians		
C1	5–30 km/h	Cyclists	Pedestrians	Motorised traffic, slow moving vehicles	Cyclepaths, cycle/footpaths
D1	5–30 km/h	Motorised traffic, pedestrians		Slow moving vehicles, cyclist	Motorway service areas
D2			Slow moving vehicles, cyclists		Station forecourts, bus stations, car parks
D3		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	Walking speed	Pedestrians		Motorised traffic, slow moving vehicles, cyclists	Pedestrian and shopping precincts
E2			Motorised traffic, slow moving vehicles, cyclists		Pedestrian and shopping precincts with loading and feeder traffic, traffic-calmed zones (home zones)

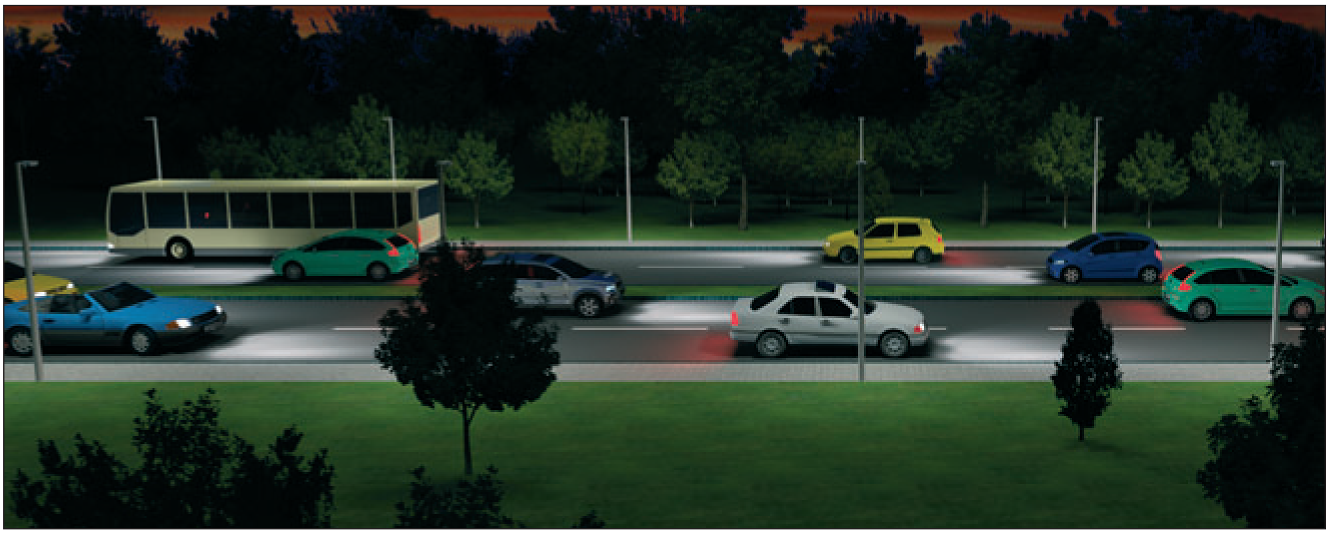


Fig. 3

Fig. 3: The lighting performance requirements for the individual lighting situations are geared to the visual tasks performed by the main users. In the lighting situations A1 to A3, only motorised traffic is a main user.

Fig. 4

Fig. 4: In lighting situations B1 and B2, traffic is mixed. Whether a road is classed as one of these lighting situations depends on whether cyclists are "other allowed users" (B1) or "main users" (B2).

Fig. 5

Fig. 5: All local access roads and residential streets with speed limits between 5 and 30 km/h, i.e. including 30 km/h zones, fall into the lighting situation categories D3 and D4.

The supplementary tables include more assessment criteria for classifying roads. These may raise the requirements which the lighting needs to meet:

- Conflict areas – this is the blanket term used in DIN 13201-1 for areas where there is a risk of collisions (see page 22)
- Vehicles parked at the side of the road – these heighten the risk of accidents
- Complexity of visual field – the impact of road lighting can be affected by visual elements in the visual field, such as advertisements, which may distract or disturb the road user.
- Ambient luminance – very bright surroundings, e.g. an illuminated sports facility, can interfere with visual perception on the road.
- Crime risk – this is assessed as the ratio of the crime rate in the actual traffic area to the crime rate in the wider area around it.
- Facial recognition – pedestrian areas are accepted as “safe” where it is possible to recognise approaching persons, anticipate their intentions and identify any potential threat.

Where road lighting or other outdoor lighting installations are planned, roads, pedestrian precincts, car parks, etc. need to be classified in accordance with DIN 13201-1 and DIN EN 13201-2, the first step of which is to establish the lighting situation (see page 6).

The road lighting parameters that need to be considered for classification beyond that are summarised in the “Lighting class planning aid (DIN 13201-1)”. The parameters it lists relate to the geometry of the relevant area, traffic- and time-dependent circumstances and other environmental influences. The answers provided help the lighting planner perform preliminary design work. Responsibility for collating the data resides with the relevant road authority. The decision parameters are also set out in relevant planning software.

Calculating road lighting in line with DIN EN 13201-3 calls for more than just addressing the lighting performance requirements set out in DIN 13201-1 and DIN EN 13201-2. The following data are also needed:

- Type, manufacturer, lamping and intensity distribution curve(s) of the calculated luminaire(s)
- Maintenance factor of the lighting installation
- Details of the geometry of the road, preferably a dimensioned road cross-section (for a regular arrangement) or an adequately scaled location plan
- Definition of the relevant area(s)
- Details of the positioning of luminaires (distance from road, staggered/facing, on one side/both sides, on central reservation, on catenary wire over the lane)
- Mounting height and horizontal distance of the light centre of the luminaire from the reference point (e.g. foot of column, kerb).

Lighting Class Planning Aid (DIN 13201-1)

Parameters	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	☐ ☐
Geometric measures for traffic calming (B, C, D)	yes no	☐ ☐
Traffic use		
Traffic flow of vehicles per day (A, B)	< 7,000 vehicles 7,000 bis 15,000 vehicles 15,000 bis 25,000 vehicles > 25,000 vehicles	☐ ☐ ☐ ☐
Traffic flow of cyclists (C, D)	Normal High	☐ ☐
Traffic flow of pedestrians (D, E)	Normal High	☐ ☐
Difficulty of navigational 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 visual field (A, B, D)	Normal High	☐ ☐
Ambient luminance (A, B, C, D, E)	Low Moderate High	☐ ☐ ☐
Main weather type (A, B) NB.: 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.

From power reduction circuits to lighting control systems, there is a whole range of opportunities to save energy with modern technology and lighting management. Because of the economies achieved, the somewhat higher acquisition cost entailed is recouped in a relatively short time. Electronic ballasts should be used wherever possible. Even in normal operation, they save energy – but incorporated in a lighting management system, they are even more efficient.

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Photo 12: Lighting control systems make road lighting flexible. They can be designed to offer various degrees of control.

Lowered night-time lighting
During the night – e.g. between the hours of 11 p.m. and 5 a.m. – the level of some road lighting can be lowered. In Germany, around half of all the exterior luminaires used in public lighting systems are powered down at night.

For single-lamp luminaires, night-lighting means reducing the lamp power of each individual light source, e.g. from 100 W to 70 W (power reduction). This preserves the uniformity of the lighting, which would not be the case in a single-lamp luminaire system where every second luminaire was simply switched off. The dark zones this would create would considerably impair the visual performance of the road user and thus severely compromise road safety.

Switching off lamps for night-time lighting is possible only where luminaires are twin-lamped (one lamp always stays on). To avoid extra maintenance costs due to lamp replacement, a changeover switching arrangement is needed to ensure that paired lamps are switched off alternately so that the life expectancy of each lamp decreases at the same rate.

With high-pressure discharge lamps, power reduction calls for ballasts with two power tappings. Changeover switching is by relay, usually powered by a switched live connection. However, there are also relays that operate without a switched live. What is important is that relays with a timer function should be used for the 100% power startup.

Lighting control systems
Lighting control systems offering various degrees of control allow lights to be activated, deactivated and dimmed independently of one another. Where this flexibility is provided, road lighting can be adapted to different conditions e.g. by sensor-controlled dimming for different times of the day, for different types of weather or for different traffic loads. Alternatively, the control system can be programmed to produce specific scenarios at preset times. This kind of lighting management enables lighting levels to be simply lowered during the night.

Smart lighting control systems have an additional advantage: constant feedback of information about the status of the connected lamps facilitates maintenance and reduces operating costs. With appropriate software, lighting control systems can be incorporated in complex traffic management systems.

Voltage reduction
Where power reduction is achieved using systems that lower the line voltage, care must always be taken to ensure that the lighting does not fall below the minimum maintained value – because the shorter the burning life of the lamps, the lower the power economy.

Operating gear
Electronic ballasts (EBs) are now widely used in road lighting, especially for operating compact fluorescent lamps. At present, EBs are rarely used for high-pressure discharge lamps. One reason for this is that the performance characteristics of conventional operating gear are already very good. Lighting installation reliability, for example, is heightened by igniters which automatically cut out at the end of a lamp's life.

Newly developed compact and extra-energy-efficient metal halide lamps, on the other hand, work only with EBs. This is what makes them so efficient. EBs also reduce the decline in luminous flux due to ageing.

False economies
Faced with the need to cut budget deficits, many local authorities decide to switch off parts of the road lighting system. This supposed economy measure may even affect whole streets, which are no longer lit late at night.

What authorities fail to realise, however, apart from the implications for public safety, is how little road lighting costs. Decisions to switch lights off are normally reversed in the wake of subsequent public protest over the “black-outs” – because a detailed study of the economics of lighting shows that:

- road lighting is not expensive,
- energy-efficient technology is a sound investment, paving the way for future economies,
- refurbishment costs are therefore quickly recouped.

Costs
Total road lighting costs consist of the costs involved in setting up and operating the system:

- capital cost of luminaires, construction elements and installation (including depreciation/interest),
- operating costs for energy, servicing/maintenance, lamp replacement.

Acquisition costs, spread over the long service life of the facilities, account for a much smaller percentage of total costs than operating costs.

Economic damage
The general breakdown of costs does not take account of the economic damage caused by accidents. This can be deduced, however, from night-time accident figures: in 2005, a total of 96,213 accidents were registered in Germany during the hours of darkness (compared with 261,349 in day-

Duty to ensure road safety

The duty to ensure road safety – enshrined in Germany in court rulings based on Section 823 of the Civil Code (Compensation) – includes a duty to provide lighting.

This is basically confined to built-up areas and stretches of road where special hazards are present, such as crossroads, T-junctions, bottlenecks, sharp bends, inclines and pedestrian crossings.

It also extends to stretches of road which are damaged or hazardous because of their layout. As such hazards present a high risk of accident, lighting is a legal requirement in these cases both within and outside built-up areas.

German court rulings are based on the latest industrial standards, i.e. the stipulations of DIN 13201-1 and DIN EN 13201. Lighting system operators’ responsibilities include monitoring the condition of the systems, right down to checking the stability of columns. Where accidents occur as a result of failure to comply with these requirements, an operator may be liable to civil or criminal prosecution. The same applies where lighting systems are not installed or operated in accordance with the duty to ensure road safety.

Photo 13: Road lighting with modern energy-efficient technology is not expensive.

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light). 46,559 were classed as serious accidents (as against 70,336 in daylight). Altogether, the 357,562 accidents in which people were hurt caused economic damage estimated at 12.8 billion euros.

costs make up a very small proportion of local authority expenditures.

Other operating costs add another 10 euros, which raises the total annual cost of operating road lighting to 17.50 euros a person.

A practical example showing that refurbishment pays off

Along a 1-kilometre stretch of road within a built-up area, luminaires fitted with high-pressure mercury vapour lamps **(a)** were replaced by new luminaires with optimised optical control systems and high-pressure sodium vapour lamps **(b)**. The 70% reduction in energy consumption cuts the electricity bill by 2,940.60 euros a year. After a payback time of less than two years, this money has a direct positive impact on accounts. Quality of lighting is also improved.

System comparison	**Old system**	**New system**
Investment costs	–	5,800 EUR
Lamping	**(a)**	**(b)**
Lamp wattage	2x125 W	1x70 W
Luminaire wattage	278 W	83 W
Luminous flux	12,400 lm	6,600 lm
Connected load	8.062kW	2.407 kW
Annual operating hours	4,000 hrs.	4,000 hrs
Annual consumption	32,248 kWh	9,628 kWh
Annual electricity costs	4,192.24 EUR	1,251.64 EUR
Annual saving	**–**	**22,620 kWh 2,940.60 EUR**

Photo 14: The cost of electricity for road lighting works out at just 7.15 euros per person a year.

Low energy consumption
Decisions to switch off street lights are often taken with a view to cutting operating costs. Since these are mostly electricity costs, such decisions are also defended on environmental grounds as an "energy conservation" measure. In actual fact, road lighting consumes comparatively little energy – accounting for just 6-7% of the electricity consumed for all the light generated in Germany – so it offers limited scope for energy conservation.

The electricity consumed (connected load) for road lighting in Germany works out at 13W per person, which makes per capita consumption 55kWh a year.

Low energy costs
The electricity bill for road lighting amounts to just 7.15 euros per person a year. So road lighting power

Refurbishment lowers costs
In some places, electricity costs are unusually high. This is almost always due to ageing lighting systems. The only remedy is refurbishment: complete renewal or a switch to

- long-life lamps with high luminous efficacy,
- cost-efficient luminaires with optimised optical control systems and
- energy-saving operating gear and circuitry.

The efficiency of new lighting systems permits greater spacing between columns, so fewer luminaires are needed to achieve the same level of lighting. That saves money – reducing both outlay and operating expenses.

Maintenance costs halved
Modern lighting technology is not just amortized

Photo 15: Operating costs other than electricity costs add another 10 euros per person a year.

through energy savings; it also lowers all other operating costs:

- Long-life lamps reduce lamp replacement costs.
- Longer lamp replacement intervals lower maintenance costs.
- Quality luminaires and mounting elements of high-grade materials are easier to maintain and require less attention. Maintenance intervals have now doubled to four years, i.e. maintenance and servicing costs have been halved.

Radiance distribution of different light sources

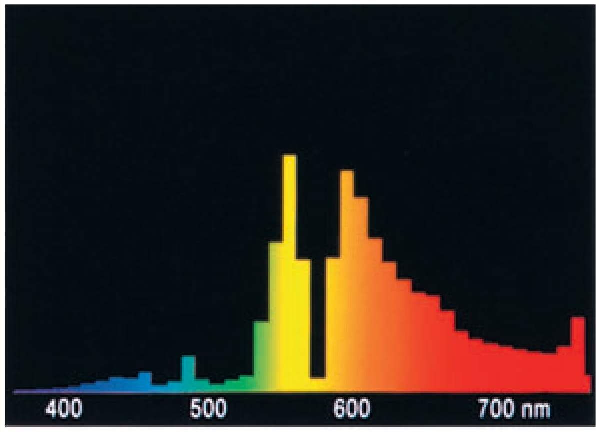


Fig. 6: Spectral radiance distribution of a high-pressure sodium vapour lamp

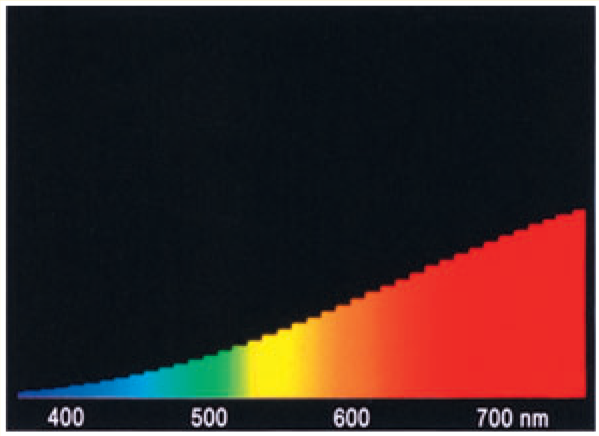


Fig. 7: Spectral radiance distribution of a general service tungsten filament lamp

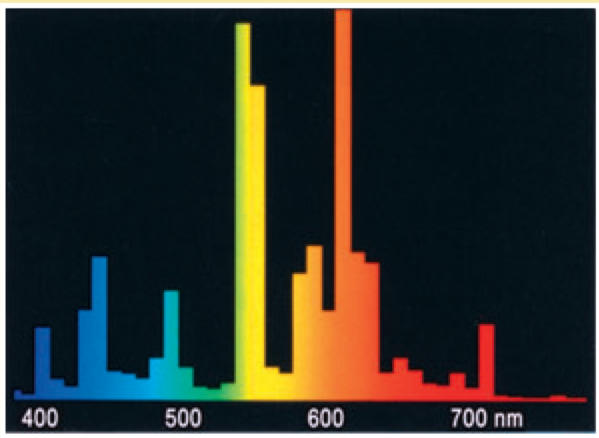


Fig. 8: Spectral radiance distribution of a warm-white fluorescent lamp

Energy consumption relatively low
From an environmental angle, one of the most important points to consider about road lighting is how much energy it consumes. The answer is: relatively little. Road lighting accounts for just 6–7% of all the electricity consumed to generate light in Germany. Nevertheless, it is right to switch to energy-saving lamps and efficient lighting technology. There is no other way to ensure there is no rise in the amount of electricity required for road lighting and no other way to downscale road lighting's role as an electricity consumer.

Incidentally, light generation as a whole accounts for only a relatively small proportion – between 10 and 11% – of total electricity consumption.

Energy balance on the road
Another comparison underlining road lighting's relatively minor role in overall energy consumption is made by the German lighting society Deutsche Lichttechnische Gesellschaft e.V. (LiTG). Calculating the energy balance of a road lined with 25 luminaires a kilometre and a traffic load of 3,000 vehicles in 24 hours, it found that stationary road lighting accounted for just 1.5% of the energy consumed; the other 98.5% was consumed by motor vehicles. Even if fuel consumption were reduced to 5 litres/100 km (1 litre petrol = 10 kWh), the energy used by road lighting would still account for less than three percent of the total.

Avoiding light pollution
Where residents are bothered by light from streetlamps shining into their homes, they have a right to complain – a right enshrined in Germany in the Federal Ambient Pollution Control Act. So any risk of "light pollution" needs to be eliminated at the planning stage.

Neither the Pollution Control Act nor its implementing regulations set out any actual ceilings or limits but the LiTG has published details of useful methods of monitoring and assessing light pollution, together with maximum admissible limits based on them (see page 38) The ambient pollution control committee of Germany's federal states (Länderausschuss für Immissionsschutz – LAI) has incorporated these methods and ceilings in its guideline "Measurement and assessment of light immissions" (see page 38) and recommends that they should be applied by environmental protection agencies; some of Germany's federal states have drafted administrative provisions for this in the form of "lighting directives".

Light and insects
Artificial lighting attracts insects, so there is a risk it could interfere with the natural habits of nocturnal animals.

Light with a predominantly yellow/orange spectral content is not so attractive to insects because their eyes have a different spectral sensitivity from the human eye. They respond more sensitively to the spectral composition of the light from fluorescent lamps and high-pressure mercury vapour lamps. Pale moonlight, which insects presumably 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. Orange and red spectral components produce virtually no response.

A summary of what science knows about this subject has been published by the LiTG (see page 38).

EU-wide environmental acceptability
Requirements designed to protect the environment are set out by the European Union (EU) in an extensive and regularly updated body of rules and regulations. Here, the EU defines four priority areas: climate protection, nature and biodiversity, environment and health, sustainable use of natural resources and waste management.

Information about the full package of measures can be found on EU Internet sites (http://europa.eu/index_en.htm) or, alternatively, on the website of the German Electrical and Electronic Manufacturers' Association ZVEI (www.zvei.org).

Reducing CO_2 emissions
The name "Kyoto" stands for the climate protection protocol that was agreed in that city and subsequently ratified by a large number of countries. Every kilowatt-hour of electricity that is not consumed reduces the carbon dioxide emissions which the protocol is designed to cut. That is why energy conservation is also climate protection.

EuP Directive
The EuP Directive (22 July 2005) is a framework directive setting eco-design requirements for energy-using products. In adopting it, the EU aims to improve such products' environmental impacts. The requirements of the EuP Directive are due to be transposed into national law by August 2007. One of the principal objectives of this legislative project is to reduce the energy consumed during a product's life. For road lighting, relevant requirements are being developed. In future, for example, the law may require that only lamps with high luminous efficacy should be used.

Old appliances
The recycling and environmentally acceptable disposal of old electrical and electronic appliances – matters regulated in the Electrical and Electronic Equipment Act (ElektroG) – are also EU-led measures to protect the environment. As far as products covered by the ElektroG are concerned, both recycling and disposal are a matter for manufacturers/importers, who have the option of assigning the task to a third party. Further information is available on the ZVEI website www.zvei.org.

Discharge lamps that have been used for road lighting are accepted for recycling in Germany by the industry joint venture Lightcycle Retourlogistik und Service GmbH (www.lightcycle.de).

Road lighting luminaires purchased after March 2006 are classed under the ElektroG as "new old appliances". They are identified by the crossed-out waste bin symbol.

Protection of the starry sky
Light emissions which radiate upwards from densely populated areas and brighten the night-time sky are known as "light smog" – and a number of European countries are trying to pass laws to guard against it. The pioneer in protecting the starry sky was the Czech Republic and Italy and Spain have followed suit. The best way to minimise this kind of light immission is to ensure that road lighting and exterior luminaires direct their light only where it is needed.

Photo 16: The uniformity of the lighting in this square is exemplary. The system uses energy-efficient lamps, luminaires and lighting technology.

16

Road lighting and safety

Accidents at night are more frequent and more serious

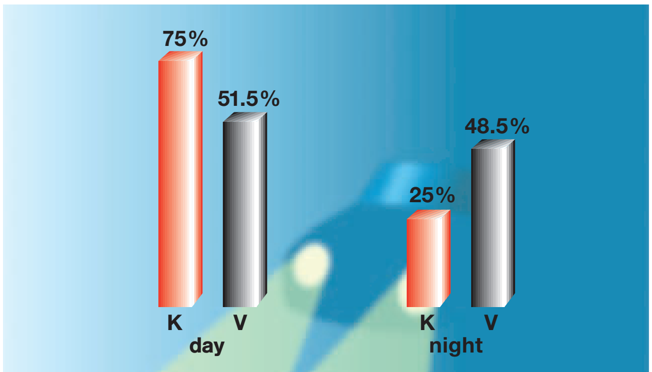
Despite lighter traffic, accidents on the roads at night are both more frequent and more serious than during the day: although night-time motoring accounts for only 25% of all kilometres driven, nearly 50% of fatal accidents occur during the hours of darkness.

This was one of the findings of a 1993 study conducted in 13 members states of the Organization for Economic Co-operation and Development (OECD) by the International Lighting Commission CIE (Commission Internationale de L'Eclairage). The figures that fuelled that finding are still valid across Europe today. Happily, the number of people killed or badly injured at night in Germany has decreased since that time but it could and should fall still further.

In 2005, the number of road deaths in Germany fell by 8.2% to 5,361, which is the lowest figure since records began in 1953. However, accidents during the hours of darkness (twilight and at night) claimed 2,143 of those lives (39.97%) and were responsible for 31.6% of cases of serious injury.

Visual performance a key factor

In part, of course, the shocking statistics are due to non-visual factors, such as fatigue, effects of alcohol, lack of motoring experience and seasonal conditions. But the root cause remains: the human eye does not perform as well in the dark as in the light. Visual acuity diminishes, distances are harder to gauge, our ability to distinguish colours is reduced, and visual performance is impeded by glare.



*Kilometres driven **(K)** and fatal road accidents **(V)** during the day and at night*

Fig. 9

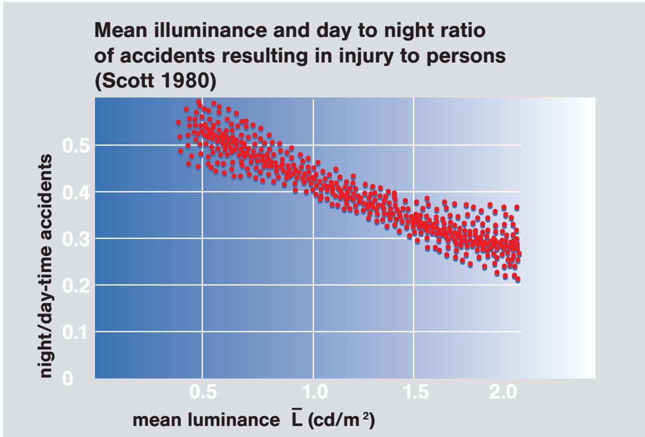


Fig. 10: Raising luminance from 0.5 to 2 cd/m² reduces the night-to-day accident ratio from 50% to 30%.

17

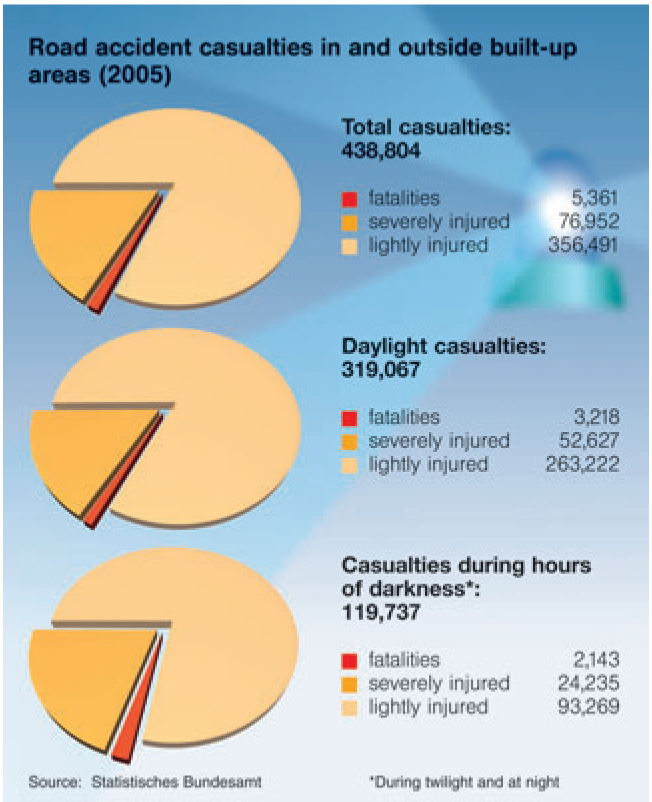
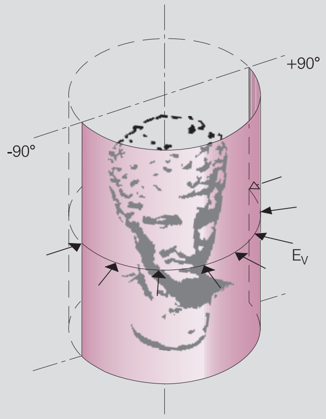


Fig. 11



Identifying faces at a distance

Good lighting is essential to enable pedestrians to identify approaching figures, anticipate their intentions and react accordingly. To permit this, semi-cylindrical illuminance (E_{SC}) needs to be at least 1 lux. Measurements are taken 1.5 metres above the ground.

Fig. 12

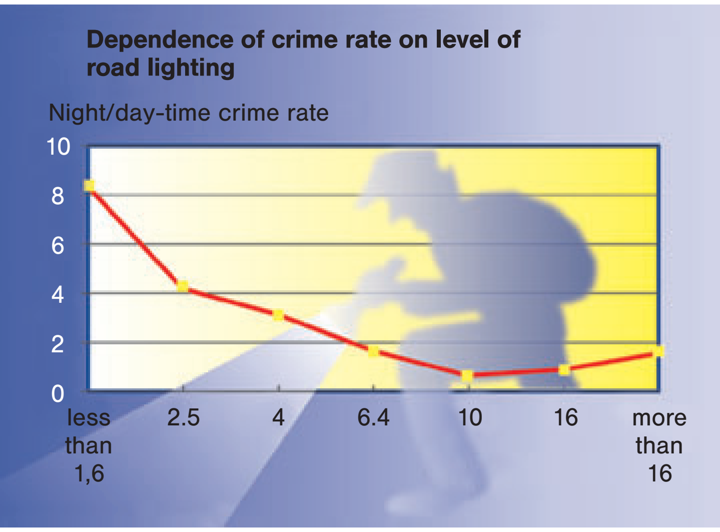


Fig. 13

Road lighting enhances road safety

We rely on our eyes for more than 80% of the sensory impressions we register. So poor visual conditions obviously reduce the amount of information that reaches our brain. That, in road traffic, is extremely dangerous. Road lighting thus makes for greater safety at night, because it helps or even actually enables us to fill the gaps in the information we receive.

More light, fewer accidents

Good road lighting improves visual performance and considerably reduces the number of accidents – by 30% overall and by 45% on country roads, and at crossroads and accident black spots. This was shown by another 1993 CIE study, which took account of every study available worldwide focused on the connection between accidents and road lighting.

Doubling the average roadway luminance significantly reduces the number of accidents that happen at night. This was shown by a before-and-after study conducted for the German Transport Ministry in 1994 on ten stretches of road in six cities: the total number of accidents decreased by 28%. The number of accidents involving pedestrians and cyclists dropped by 68% and the number of casualties fell by 45%.

Light prevents crime

Good, correct lighting also prevents crime. Experience has shown that acts of violence and crimes against property are mostly committed in dark, secluded places. Those who commit them are less inhibited in such places because there is less risk of being identified and because potential victims are insecure and more vulnerable.

Higher horizontal illuminance – together with high vertical illuminance where the presence of pedestrians is pronounced (see Fig. 12) – makes for better visual perception: suspicious movements are spotted farther away, details and the intentions of approaching figures are made out more clearly. Fast and reliable identification gives us more time to prepare for danger and react accordingly.

Numerous studies have shown that increased illuminance produces a sharp decrease in night crime (see Fig. 13). They also confirm that a higher lighting level gives residents a greater sense of security, which makes for a better neighbourhood and a better quality of life.

Photos 17, 18 and 19: Street, path and square lighting makes for greater safety. It helps prevent accidents and guards against crime.

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A1, A2, A3 lighting situation roads

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
A1	> 60 km/h	Motorised traffic		Slow moving vehicles, cyclists, pedestrians	Motorways and roads for motor vehicles only
A2			Slow moving vehicles	Cyclists, pedestrians	Major country roads, poss. with separate cycle- and footpath
A3			Slow moving vehicles, cyclists, pedestrians		Minor country roads

Lighting requirements
Roads for fast motorised traffic are classed as lighting situations A1 to A3. On these roads, visual conditions need to be primarily geared to the navigational task (visual task) of the person in control of the vehicle. The motorist needs to be able to recognise and assess the road ahead, the state and boundaries of the carriageway, road signs, other vehicles and road users as well as obstacles on the roadway and hazards from the side of the road.

The surface of the road plays a major role in luminance calculations. This is because objects are visible only if their luminance contrasts adequately with that of their surroundings, which from the motorist's viewpoint is mainly the roadway. Since higher ambient luminance makes for greater contrast sensitivity, it is necessary to provide enough roadway luminance to ensure that objects stand out visually from their surroundings (roadway).

The arrangement of luminaires in a road lighting system provides visual guidance. Special hazard zones, such as T-junctions or crossroads, need to be identifiable well in advance.

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of road and situation in question. Tables indicate the minimum lighting values required.

Mean roadway luminance is the yardstick used for assessment. How bright a road appears – its luminance – depends on the position of the observer, the arrangement of luminaires, the reflective properties of the road surface, the luminous flux of the lamps and the way the light is distributed by the luminaires.

Photo 20: Luminaires are not positioned on the central reservation on bends. Closer spacing in the middle of the bend makes for better visual guidance.

20

Other variables that have an important bearing on road lighting quality are longitudinal and overall uniformity (see page 4) and glare limitation, which needs to be adequate and has to take account of admissible threshold increments (see page 4).

Where road lighting ends or drops to a lower lighting level, the decrease in luminance should be gradual. This transition zone makes it easier for the eye to adapt to the darker conditions – which is harder than adapting from darkness to light.

21

Photos 21 and 22: On roads classed as A lighting situations, visual conditions need to be primarily geared to the navigational task (visual task) of the motorist.

Photo 23: The road ahead, the state and boundaries of the carriageway, road signs and any hazards on or from the side of the road are clearly recognisable.

Photo 24: As a conflict area, a roundabout demands special attention from the lighting designer (see page 22).

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B1, B2 lighting situation roads

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
B1	30–60 km/h	Motorised traffic, slow moving vehicles	Cyclists, pedestrians		Trunk roads, through roads, local distributor roads
B2		Motorised traffic, slow moving vehicles, cyclists	Pedestrians		

Lighting requirements
Nearly all roads in built-up areas that are not subject to a special speed limit are classed as B lighting situations. These are divided into two types, depending on how the mixed traffic with cyclists is accommodated: B1 where the cycle traffic is basically separated from the motorised and slow moving traffic (cyclepath), B2 where cyclists and the other vehicles use the roadway together.

Apart from cyclists being classed as "other allowed users" or "main users", there are other parameters that can result in higher lighting requirements. These include physical traffic-calming measures, intersection density, traffic flow of vehicles, difficulty of navigational task, conflict area, complexity of visual field, parked vehicles, ambient brightness and traffic flow of cyclists.

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of road and situation in question. Tables indicate the minimum lighting values required.

Mean roadway luminance is the lighting quantity used for assessment. Other variables that have an important bearing on road lighting quality are longitudinal and overall uniformity (see page 4) as well as adequate glare limitation.

In conflict areas or on bends or short sections of road, luminance cannot be assessed, so mean illuminance and illuminance uniformity are used as yardsticks instead. The determining factor here is the lighting class of comparable lighting level according to DIN 13201-1.

For higher lighting requirements, DIN 13201-1 includes a detailed selection matrix in which the complex interaction of diverse factors is systemised by assignment of assessment parameters to lighting classes. This table basically assumes "normal conditions". There must be good reasons for assessments to deviate from the norm.

Features that might make the scenario for the navigational task (visual task) more difficult than usual, for example, include "side-switching parking bays with analogous lane definition" or "curved road with gradient". In a shopping street, the complexity of the visual field may be higher than "normal", for example, because of constant changes in ambient brightness due to illuminated sign advertising.

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Photo 25: Roads classed as B lighting situations are mixed traffic areas with several main users.

Cyclepaths and footpaths adjacent to the roadway as well as verges can be designed to meet individual requirements. This is recommended particularly where cross-sections are generous. Where no special requirements are defined, minimum illumination of the roadway boundaries and adjacent areas needs to be ensured by an adequate ambient illuminance ratio (SR: surround ratio). As a matter of principle, the brightness level of adjacent foot- or cyclepaths needs to be adjusted to suit the brightness of the roadway.

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Photos 26 and 27: B road lighting needs to meet high requirements. Here too, mean roadway luminance is the defining parameter. In conflict areas, on bends or on short sections of road, mean horizontal illuminance is used as a yardstick instead.

Photos 28 and 29: Luminaires for B roads can be functional, as in this residential area (28), or decorative, as in this downtown street (29).

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D3, D4 lighting situation roads

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
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)

Lighting requirements
The lighting situations D3 and D4 cover all local access roads and residential streets with speed limits up to 30 km/h. The primary purpose of the lighting here is to protect the "weaker" road users in the traffic mix, whose accident risk exposure is the greatest.

This applies, in particular, to local access roads and residential streets without footpaths (D4). Here, the interests of pedestrians are paramount, which is why it is important that cyclists and motorists should keep a clear overview. The reduced speed helps them do this – so does correct lighting.

Another, equally important task is crime prevention, which forms part of a local authority's duty of care for the community. Depending on how high the crime risk is rated, illuminance levels may need to be raised (see pages 8 and 15).

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of road and situation in question. Tables indicate the minimum lighting values required.

Because they often have different surfaces, local access roads and residential streets are not suitable for luminance-based assessment for lighting. For D3 and D4 roads, the average maintained horizontal illuminance should be 2–15 lx and the minimum illuminance over the assessment field 0.6–5 lx.

The lighting needs to illuminate more than just the roadway. It should also provide adequate, uniform illuminance for adjacent areas such as cyclepaths, footpaths and building facades. Care must be taken here to avoid "light pollution" due to excessively high illuminance near windows (see page 12).

Appropriate semi-cylindrical illuminance (see "Identifying faces at a distance", page 15) of 0.5–3 lx facilitates recognition of oncoming persons, permits a faster response to a perceived threat and can thus help guard against criminal assault.

Apart from performing actual lighting functions, luminaires in local access and residential streets help shape the face of the street and define the residential environment. Even the light they distribute plays a role in urban design: warm light colours create a "homely" atmosphere.

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Photo 30: Downtown road lighting – the luminaires shape the face of the inner city precinct, their light underpinning attractive urban design.

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Photos 31 and 32: *There is no stipulated mounting height for light sources. Even for local access roads and residential streets, relatively high mounting heights are an option (32). The key design quantity is mean horizontal illuminance.*

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Photos 33 to 35: Typical local access roads and residential streets in residential areas. Remember: the lighting needs to illuminate more than just the roadway. It should also provide sufficient illuminance for adja-cent areas.

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Conflict areas

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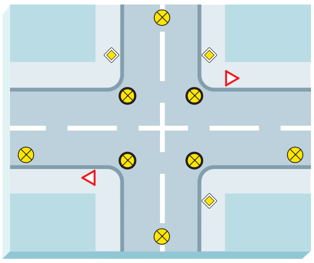

Photo 36: Crossroads – as an area of heightened risk exposure, this conflict area requires a lighting level that takes account of the higher risk as well as good uniformity of lighting.

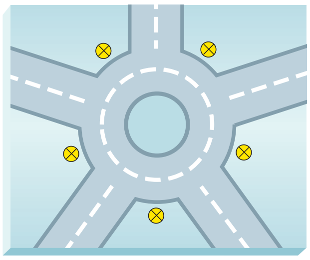

Photo 37: The way traffic streams intersect each other at a roundabout differs from the kind of "conflict" found at crossroads. However, the risk remains the same, which is why roundabouts are also classed as conflict areas.

Lighting requirements
Proceeding straight ahead on a road for motorised traffic is fairly unproblematic. At least there are few conflict areas there. Where the traffic situation is more complex, however, and road users more numerous, collision risk increases. And where different types of road user are present – motorists, cyclists, pedestrians – in different numbers, the potential level of conflict is even higher.

Conflict areas include all areas where road users typically travel at speeds exceeding 30 km/h and where motorised traffic streams intersect one another or overlap areas frequented by other types of road user. Examples are crossroads and T-junctions, pedestrian crossings, cyclepath crossings and roundabouts.

Pedestrian crossings controlled by traffic lights may be treated for lighting purposes as a conflict area of the road in question. However, crossings with StVO sign 293 need to be illuminated in accordance with DIN 67523 (see page 23).

Assessment criteria
Because conflict areas are areas of heightened risk exposure, they require a level of lighting that takes account of the higher risk as well as good uniformity of lighting. As no single observer position can be defined to determine luminance, the assessment criteria used are level and uniformity of mean horizontal illuminance. Care must be taken here to ensure that glare from the luminaires installed is sufficiently suppressed.

Conflict areas require a lighting level at least as high as that of the approach road with the highest luminance. CE lighting class selection is regulated by DIN 13201-1. Where the requirements of the road are generally low, conflict area lighting needs to be raised more than for roads with generally high requirements.

Photo 38: The more complex the traffic situation, the higher the risk of collision.

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Lighting requirements
As every child knows, the safest place to cross the road is at specially signed and controlled crossing points. These include light-controlled crossings and crossings identified by sign 293 of the German road traffic ordinance (StVO).

Light-controlled pedestrian crossings can be treated for lighting purposes as a conflict area of the road in question. To ensure that pedestrians are always identifiable on a non-light-controlled crossing with StVO sign 293, high vertical illuminance is required for both the crossing itself and the waiting areas at either side. This can only be delivered by supplementary lighting.

Where the road lighting at either side of a pedestrian crossing with StVO sign 293 meets at least the requirements of lighting class ME2 over a fairly long stretch of road at night, it is deemed adequate for the crossing. In such cases, there is thus no need for supplementary lighting.

Assessment criteria
Rules governing the design and equipment of pedestrian crossings with StVO sign 293 are established for crossings all over Germany in the “Richtlinien für die Anlage und Ausstattung von Fußgängerüberwegen – R-FGÜ 2001”. This stipulates that supplementary lighting must be stationary and compliant with the lighting requirements set out in DIN 67523.

Motorists identify pedestrians best when they see them as light objects against a dark background (positive contrast). This is achieved by positioning a luminaire between the motorist and the crossing so that light is cast sideways onto the pedestrian in the direction of travel. Depending on the intensity distribution of the luminaire, it should be positioned at a distance of between half a mounting height (0.5 x h) and a full mounting height (1.0 x h) from the pedestrian crossing (see Fig. 17).

The highest illuminance should be directed onto the pedestrian in the middle of the crossing. To avoid dazzling motorists, luminous intensity in the opposite direction – i.e. in the direction of an approaching vehicle - needs to be severely limited. These requirements are met only by special optical control systems incorporated into dedicated pedestrian crossing luminaires.

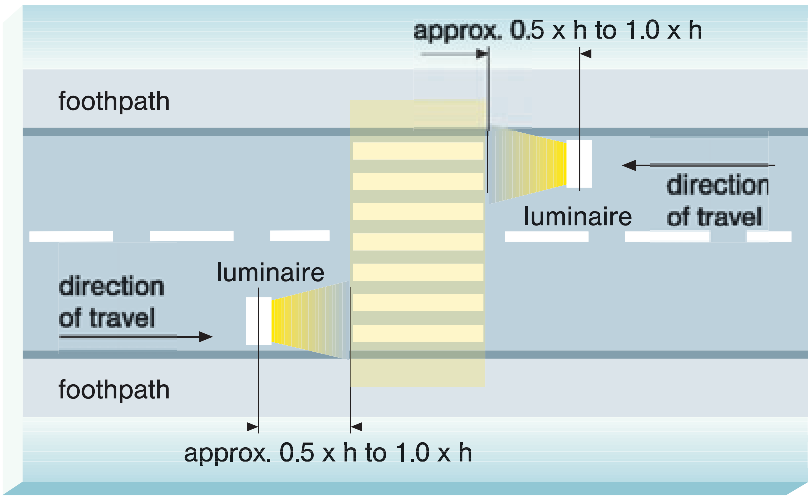

Fig. 17: Illuminating pedestrians from the side in the direction of travel (positive contrast); “h” is the mounting height of the luminaire.

Photos 39 and 40: Supplementary lighting at crossings makes pedestrians visible.


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Traffic-calmed zones (E2)

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
E2	Walking speed	Pedestrians	Motorised traffic, slow moving vehicles, cyclists		Pedestrian and shopping precincts with loading and feeder traffic, traffic-calmed zones (home zones)

Lighting requirements
Traffic-calmed zones identified by StVO sign 325 – roughly equivalent to 'home zones' – are covered by lighting situation E2. The primary purpose of lighting here is to protect the "weaker" road users, who are exposed to the greatest risk of accident in the jointly used (mixed) traffic area.

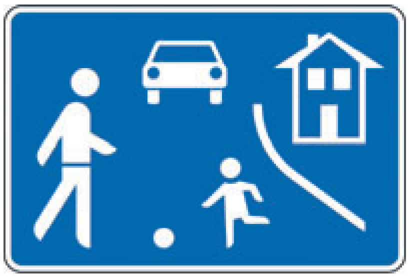
Safeguarding pedestrians and children at play means ensuring that motorists and cyclists keep a clear overview. The very low speed limit of 4–7 km/h (walking speed) helps them do this – so does correct lighting.

Another, equally important task is crime prevention. Depending on how high the crime risk is rated, illuminance levels may need to be raised (see pages 8 and 15).

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of road and situation in question. Tables indicate the minimum lighting values required.

Like pedestrian precincts, traffic-calmed areas often have different roadway surfaces, so they are not suitable for luminance-based assessment for lighting. Depending on pedestrian traffic flow, the average maintained horizontal illuminance for an E2 lighting situation should be 3–20 lx and the minimum illuminance over the assessment field 0.6–8 lx.

The lighting needs to illuminate more than just the roadway. It should also provide adequate, uniform illuminance for adjacent areas. Care must be taken



here to avoid "light pollution" due to excessively high illuminance near windows (see page 12).

Appropriate semi-cylindrical illuminance (see "Identifying faces at a distance", page 15) of 0.5–5 lx facilitates recognition of oncoming persons, permits a faster response to a perceived threat and can thus help guard against criminal assault.

Apart from performing actual lighting functions, luminaires in traffic-calmed areas help shape the face of the street and define the residential environment. Even the light they distribute plays a role in urban design: warm light colours create a "homely" atmosphere.

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Photo 41: In this traffic-calmed street, speed is restricted to walking speed.

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Photo 42: Motorists entering home zones identified by StVO sign 325 need to be extremely alert.

Cyclepaths (C1)

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
C1	5–30 km/h	Cyclists	Pedestrians	Motorised traffic, slow moving vehicles	Cyclepaths, cycle/footpaths

Lighting requirements
Cyclepaths run right alongside the footpath; alternatively, the two may be combined, i.e. used by both cyclists and pedestrians. Correct lighting allows path users to be promptly identified and thus helps prevent collisions. It also makes hazards, such as potholes or bumps, easier to make out, which reduces the risk of accidents, especially for cyclists travelling fast.

In built-up areas, correctly planned street lighting also caters for cycle paths flanking the roadway. For cyclepaths in parks and gardens, set back from main roads or outside built-up areas, dedicated lighting is required. Here, special attention should be paid to uniformity of lighting because perception of hazards is severely impaired by patches of darkness.

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of traffic route and situation in question. Tables indicate the minimum lighting values required.

Depending on the traffic flow of cyclists and the ambient brightness, the average maintained horizontal illuminance should be 2–15 lx and the minimum illuminance over the assessment field 0.6–5 lx.

Appropriate semi-cylindrical illuminance (see “Identifying faces at a distance”, page 15) of 0.5–3 lx makes for better perception and can thus help guard against criminal assault.

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Photos 43 to 45: Along cyclepaths in parks and gardens, set back from main roads or outside built-up areas, dedicated lighting makes for safety.

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Pedestrian precincts and squares (E1)

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
E1	Walking speed	Pedestrians		Motorised traffic, slow moving vehicles, cyclists	Pedestrian and shopping precincts

Lighting requirements
Pedestrian precincts and squares are classed as lighting situation E1. Where they are also used for loading operations, however, the requirements for lighting situation E2 apply (see page 24).

When choosing lighting for pedestrian precincts and public squares, particular attention needs to be paid to decorative criteria. Luminaires must harmonise with the surrounding architecture and harness light to create atmosphere. However, this requirement must not be met at the expense of safety. Lighting should also help prevent crime and make obstructions and hazards identifiable well in advance.

Attractively designed pedestrian precincts heighten the intensity of the downtown experience and generate more trade for retailers and restaurateurs. This aesthetic requirement is met during the day and at night by decorative luminaires and columns in historical or modern designs chosen to suit the surroundings. Floodlighting is an additional design option (see page 29).

Another, equally important task is crime prevention. Depending on how high the crime risk is rated, illuminance levels may need to be raised (see pages 8 and 15).

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of traffic routes/areas and situation in question. Tables indicate the minimum lighting values required.

For exclusively pedestrian traffic (E1) – and depending on traffic flow – the average maintained horizontal illuminance should be 2–20 lx (E2: 3–20 lx) and the minimum illuminance over the assessment field 0.6–8 lx (E2: ditto).

Appropriate semi-cylindrical illuminance (see “Identifying faces at a distance”, page 15) of 0.5–5 lx (E2: 0.75–5 lx) makes for better perception and can thus help guard against criminal assault. What it always does, as well, is increase people’s sense of security.

Photo 46: Attractively designed inner-city space heightens the intensity of the downtown experience. Good-looking lighting makes a major contribution.

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Photos 47 and 48: Where all traffic is pedestrian, public squares and pedestrian precincts are classed as lighting situation E1; if loading traffic is allowed, the somewhat higher requirements of situation E2 apply.

Photos 49 and 50: In pedestrian precincts and public squares, special attention needs to be paid to the decorative impact of luminaires and light. However, this should not be at the expense of security.

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Sturdy design

The right choice of luminaire guards against vandalism and theft: strong, compact quality luminaires stand up well to mechanical stress. The sturdiest designs are described as “vandal-proof”. Where wall luminaires are within easy reach, for example, the risk of glass breakage is avoided by impact-resistant plastic enclosures. However, even the toughest luminaire cannot withstand sustained exposure to rough treatment.

As for other environmental factors, the higher a luminaire’s degree of protection, the less susceptible it is to damage. At the same time, a higher degree of protection makes for a longer luminaire life. The minimum degrees of protection recommended are IP23 for the luminaire wiring compartment and IP54 for the lamp compartment.

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Parks and gardens

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
E2	Walking speed	Pedestrians	Motorised traffic, slow moving vehicles, cyclists		Pedestrian and shopping precincts with loading and feeder traffic, traffic-calmed zones (home zones)

Lighting requirements
Lighting for parks and public gardens is not specifically regulated by standard. Fördergemeinschaft Gutes Licht recommends that lighting situation E2 should be **applied analogously**.

The primary function of lighting in parks and public gardens is to heighten public safety: luminaires along paths show us the way, help us get our bearings and enable us to make out the ground we are walking on and any obstructions or hazards on it. Another, equally important safety aspect is crime prevention.

As well as performing these practical functions, however, path lighting also serves a decorative purpose – during the day as well as at night. Off-path floodlighting is purely decorative: it provides attractive accentuating light, creates atmosphere and heightens a park's appeal.

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) – in this case analogously – ensures that the appropriate lighting requirements are met for the type of traffic routes/ areas and situation in question.

The level of lighting required depends on the ambient brightness. The average maintained horizontal illuminance should be 3–20 lx and the minimum illuminance over the assessment field 0.6–8 lx . For paths with stairs, steps or an uneven surface, a higher lighting level is recommended.

Providing additional vertical lighting components significantly lowers the risk of criminal assault (see "Identifying faces at a distance", page 15). Semi-cylindrical illuminance should be 0.5–5 lx. Higher vertical lighting components have a positive psychological impact: they reduce disquiet about the darkness in the farther reaches of the park.

The general rule for path luminaire spacing is: the lower the mounting height, the shorter the distance required from one luminaire to the next. In addition to this, however, spacing also depends on the course of the path and obstructions to visibility in the park.

There are virtually no design restrictions on lighting for illuminating trees, bushes, flowerbeds, fountains, ponds or other park features. For these "lighting productions", dark zones are a positive requirement to heighten the impact of the objects illuminated. One thing which is important to remember, however, is that passers-by must not be dazzled (direction of light = viewing direction) and there should be no risk of light from the park disturbing local residents in their homes (see page 12).

51

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Floodlighting

As photo 52 shows, floodlighting creates decorative “night pictures”: entire buildings, building sections or facades, art objects, fountains and trees become eye-catching features and enhance the appeal of their surroundings.

Observers are not dazzled where lighting and viewing directions are the same. Light that might disturb local residents in their homes (see page 12) can be prevented by careful planning. Installing floods at an adequate distance avoids excessively deep shadows on the object which is illuminated.

The illuminance required depends on the colour and reflectance of the object illuminated (object luminance) as well as on the ambient brightness: the darker the object and the brighter the surroundings, the more light is required.

Particularly effective “night pictures” are created where the colour appearance of the lamps is selected to suit the material of the object illuminated: high-pressure sodium vapour lamps bathe sandstone in a gentle yellowish light and emphasise the colour character of red leaves. Metal halide lamps underline the gleam of metal and glass facades and are suitable for yellow or yellowish green as well as dark green or blue-green leaves.

55

56

Photos 53 and 54: The path lighting reveals anything a visitor might stumble over and acts as a deterrent against crime.

Photo 51: Lighting in parks and gardens makes for greater security. The luminaires show where the path goes and thus help visitors get their bearings.

Photos 55 and 56: In parks and gardens, lighting can develop its full decorative potential – either on a small scale (55) or on a large one (56).

Outdoor car parks (D2)

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
D2	5–30 km/h	Motorised traffic, pedestrians	Slow moving vehicles, cyclists		Station forecourts, bus stations, car parks

Lighting requirements
Outdoor car parks are classed as lighting situation D2. The principal purpose of outdoor car park lighting is to enhance traffic safety: it aids orientation and makes persons, vehicles, boundaries and obstructions easier to distinguish. What is more, a good level of lighting with high vertical illuminance acts as a deterrent for burglars, car thieves and assailants.

For vehicle traffic in particular, approach roads, entrances and exits are accident black spots. The risk of accidents is reduced by signal arrangements of supplementary luminaires delivering higher illuminance.

57

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of traffic routes/areas and situation in question. Tables indicate the minimum lighting values required.

Depending on the traffic load of the car park, the average maintained horizontal illuminance should be 7.5–20 lx and the minimum illuminance over the assessment field 3–8 lx. Semi-cylindrical illuminance of 1.5–5 lx takes account of the vertical illuminance required to make out the faces of oncoming persons; it thus helps guard against crime (see page 15).

Photo 57: The decorative vegetation must not block the light of the luminaires.

58

59

Photos 58 and 59: The car park lighting aids orientation and makes persons, vehicles, boundaries and obstructions easier to distinguish.

60

Photo 60: The arrangement of parking spaces dictates the arrangement of luminaires. Mounting heights up to 12 metres are appropriate for a large outdoor car park like this.

Station forecourts and bus stations (D2)

Situation	Speed of main user	Main users	Other allowed users	Excluded users	Application examples
D2	5–30 km/h	Motorised traffic, pedestrians	Slow moving vehicles, cyclists		Station forecourts, bus stations, car parks

Lighting requirements
The primary purpose of station forecourt and bus station lighting is to ensure passenger safety. It should be easily possible for passengers to identify stopping areas and clearly distinguish ground, steps and floor when entering and exiting vehicles. To ensure this, these traffic areas need dedicated lighting that enables pedestrians and bus drivers to get reliable bearings.

The lighting should also lower the risk of crime: depending on how high the crime risk is rated, illuminance levels may need to be raised (see pages 8 and 15).

Assessment criteria
Following the selection procedure set out in DIN 13201-1 and applying the decision criteria it requires (see page 6) ensures that the appropriate lighting requirements are met for the type of traffic routes/ areas and situation in question. Tables indicate the minimum lighting values required.

For station forecourts and bus stations, the average maintained illuminance should be between 7.5 lx and 20 lx.

Appropriate semi-cylindrical illuminance (see “Identifying faces at a distance”, page 15) of 1.5–5 lx makes for better perception and can thus help guard against criminal assault.

61

Photo 61: Station forecourts need dedicated lighting. Its purpose is to facilitate orientation and guard against accidents and criminal assault.

62

Photos 62 and 63: The light is required to enable passengers to identify stopping areas and bays and to clearly distinguish ground, steps and floor when entering and exiting vehicles.

63

In view of the seriousness of an accident in a tunnel and after the large number of accidents that have occurred in recent years, the need for greater safety is obvious. Effective lighting outside and inside a tunnel helps raise safety standards significantly. It plays a crucial role in making tunnels safe for traffic.

Lighting requirements
The risk of accidents is particularly high during the day: the difference in visual conditions between daylight outside and a comparatively dark tunnel entrance and transition zone requires intense visual concentration. Adaptation from dark to bright conditions at the tunnel exit is not so critical.

A distinction needs to be made between short and long tunnels. In an optically long tunnel, the exit is not visible from the stopping distance. CIE publication 88 makes a distinction between short, optically long and geometrically long tunnels. Short tunnels (defined in CIE 88 as tunnels up to 25 m long) do not require lighting.

Tunnel lighting needs to be tailored to the adaptive capacity of the human eye. Viewed from outside, a tunnel entrance looks like a black hole. What helps here is a high level of lighting, which should be lowered only gradually over the entrance zone and a subsequent transition zone.

For the rest of the tunnel interior, a relatively low level of lighting is sufficient. In order to counteract the sensation of oppressive confinement within the tunnel, however, it should be somewhat higher than that of the road lighting outside. In the exit zone, it is advisable to raise the lighting level to make for a safer transition to daylight brightness.

Today, to facilitate identification of the edges of the roadway inside a tunnel, small LED lights are mounted on the raised kerbstones. They also help make the course of the road ahead more clearly discernible.

For underpasses with pedestrian traffic, it is advisable to keep lighting at a high level throughout. The mean horizontal illuminance should be supplemented by adequate vertical illuminance (semi-cylindrical illuminance, see page 15). Even short underpasses require artificial lighting. This is because they normally have only small cross-sections, which means daylight decreases rapidly within metres. Large underpasses in city centres or underground railway systems are not classed as exterior lighting applications.

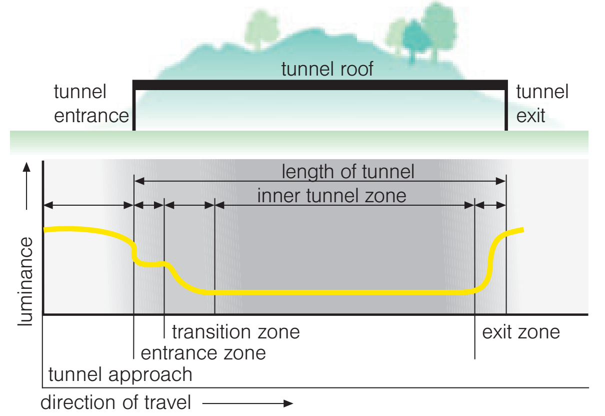


Fig. 19: Luminance in a road tunnel

Assessment criteria
Requirements for tunnel lighting are set out in DIN 67524, Parts 1 and 2. Part 1 is currently being revised and is due for publication between the middle and end of 2007. The revised standard will additionally cover requirements for emergency lighting and fire emergency lighting.

The assessment criterion for road tunnel lighting is luminance. The luminance level required varies according to adaptation luminance, traffic density and speed limit. At present, tunnels on German motorways and major roads are designed in accordance with the road tunnel equipment and operation guideline RABT 2006. The guide values for lighting relate to roadway and walls.

Changes in luminance level between tunnel entrance


64

Photo 64: Effective lighting outside and inside a tunnel makes for significantly greater safety.

65

66

and exit need to be tailored to the adaptive capacity of the eye (see “Lighting requirements”). Figure 19 shows how the luminance varies.

Adjusting luminance in the entrance and transition zone to the level of luminance outside is a task for special control systems with luminance sensors. Tunnel lighting is a job for specialists. Because no tunnel is the same as another, lighting system requirements also differ from one project to the next.

The criterion for assessing underpass lighting is illuminance. During the day, the recommended, tried-and-tested value for mean horizontal illuminance is 100 lx; at night, 40 lx is sufficient. Semi-cylindrical illuminance needs to be at least 25 lx and 10 lx respectively. In addition, care should be taken to ensure uniformity of lighting and adequate glare limitation.

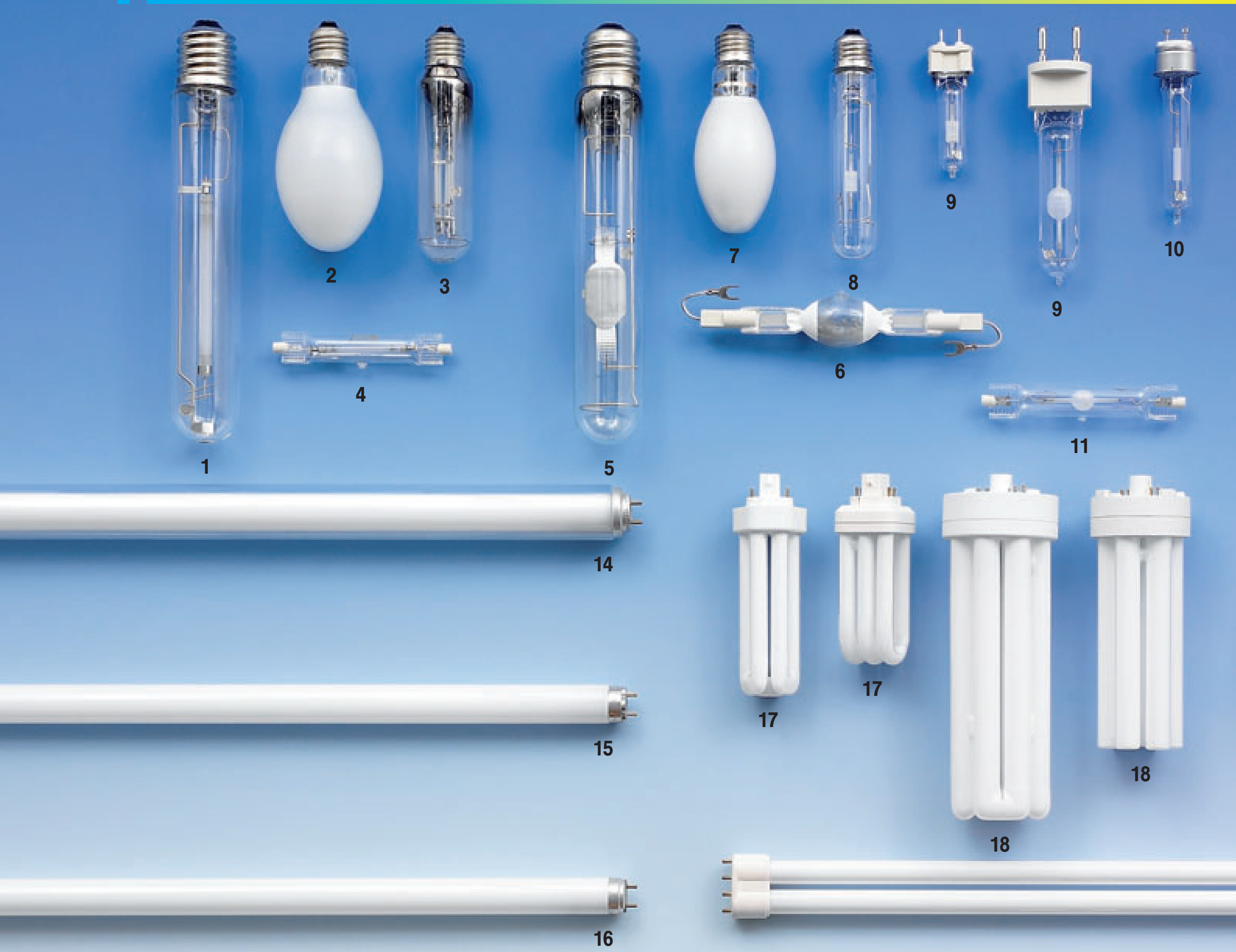
Photos 65 and 66: A tunnel entrance during the day and at night – a high lighting level in the threshold zone prevents the tunnel entrance looking like a black hole.

Photos 67 to 69: For pedestrian underpasses, a high level of lighting is required throughout.

67

68

69



Lamp type	1	2	3	4	5	6	7	8	9	10
	tubular (T)	ellipsoid (E)	T or E with double burner	with base at both ends	tubular (quartz)	with base at both ends	ellipsoid (quartz)	tubular or ellipsoid (ceramic)	tubular (ceramic)	
Type of lamp / Features	High-pressure sodium				Metal halide					
Power rating classes (Watt) from	50	35	50	70	250	1.000	35	70	35	60
to	1.000	1.000	400	400	2.000	2.000	1.000	250	250	140
Luminous flux (Lumen) from	4.400	2.200	4.000	6.800	20.000	90.000	2.850	5.600	3.100	6.850
to	130.000	128.000	55.000	48.000	240.000	230.000	100.000	22.500	25.000	16.500
Luminous efficacy (Lumen/Watt) from	70	63	66	97	80	86	74	80	85	114
to	150	139	138	120	120	115	100	90	100	118
Light colour	ww	ww	ww	ww	nw, dw	nw, dw	ww, nw, dw	ww	ww, nw	ww
Colour rendering index R_a (range)	< 40	< 40	< 40	< 40	60 – 90	60 – 95	69, 80 – 95	80 – 85	80 – 95	60 – 70
Base	E27 E40	E27 E40	E27 E40	Fc2 RX7s	E40	Special	E27 E40	E27 E40	G12 G22	PGZ12

The principal selection criteria for road lighting lamps are energy balance (luminous efficacy) and service life. Closely connected with these is the decision on wattage (W). Light colour and colour rendering properties are less important here than for interiors (see page 5).

Luminous efficacy
Luminous efficacy is the measure of a lamp's efficiency, expressed in lumens (lm) per watt: the higher the ratio of lumens to watts, the more light a lamp produces from the energy it consumes. An ordinary tungsten filament lamp generates only 12 lm/W, whereas the luminous efficacy of discharge lamps is several times higher (see table). Discharge lamps operated by electronic ballasts achieve even greater efficiency.

Service life
Service life is the length of time a lamp is operated before it becomes unserviceable. Average service life is defined as the average electrical service life (survival rate) of a number of lamps operated under standard conditions. Manufacturers publish service life ratings, indicating the switching rhythm and the failure rate on which they are based. When individual lamps fail, road safety is compromised. So spent lamps should be replaced immediately. Group replacement intervals are determined by the failure rate tolerated. This is normally 5%.

The longer a lamp operates before it needs to be replaced, the lower the cost of re-lamping and maintenance. Detailed comparative data on the service life of discharge lamps is available from the electrical lamp association (Fachverband Elektrische Lampen) within the German electrical and electronic manufacturers' association ZVEI (see "Standards and Literature", page 38).

tubular (ceramic)

with base at both ends	ellipsoid	tubular	longlife Ø 38 mm, for low temperatures	longlife Ø 26 mm	fluorescent lamp Ø 26 mm	1, 2- and – illustrated – 3-tube lamp	3- or 4-tube lamp	elongated[2)]	bulb-shaped	ring-shaped
11	12	13	14	15	16	17	18	19	20	21
	Mercury vapour	**LP sodium**	**Tubular three-band fluorescent**			**Compact fluorescent**			**Induction**	
70 400	50 1.000	18 180	18 58	18 58	18 58	5 70	60 120	18 80[3)]	55[4)] 165[4)]	70 150
5.100 37.000	1.600 58.000	1.800 32.000	1.350 5.150	1.350 5.150	1.350 5.200	250 5.200	4.000 9.000	1.200 6.000	3.650 12.000	6.500 12.000
73 100	32 60	100 178	75 89	75 89	75/81[1)] 93/100[1)]	50 82	67 75	67 87	64[4)] 73[4)]	75[4)] 79[4)]
ww, nw	ww, nw	–	ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, nw	ww. nw	ww, nw	ww, nw	ww, nw
75 – 96	36, 45 – 60	–	80 – 85	80 – 85	80 – 85	80 – 85	80 – 85	80 – 85	80 – 85	80 – 85
Fc2 RX7s	E27 E40	BY22d	G13	G13	G13	G23 G24, 2G7 GX24	2G8-1	2G11	Special	Special

1) Where lamps are EB-operated, luminous efficacy increases to 81-100 lm/W.
2) 18–55 W also as special design for outdoor lighting
3) 40 W and 55 W only with EB
4) System (lamp + EB)

ww = warm white
colour temperature below 3,300 K
nw = neutral white
colour temperature 3,300 to 5,300 K
tw = daylight white
colour temperature over 5,300 K

Luminaires

Luminaire selection is determined by the lighting requirements of the lighting task as well as by mechanical and electrical requirements and the design intent.

It makes good economic sense to choose quality luminaires. Key features of their design and production are:

- economical operation (high utilisation factors)
- lighting quality and functionality
- mechanical and electrical reliability (VDE, ENEC)
- long life (materials, finish, compact design)
- production quality control
- simple assembly and maintenance-friendly design
- professional advice and planning aids.

Figs. 20 + 21

Post-top luminaires, a preferred option for A and B lighting situation roads

Figs. 26 + 27

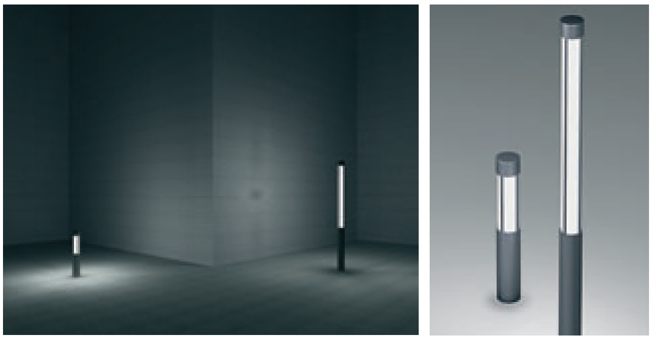
Pendant luminaires for suspension on catenary (overhead) wires, a preferred option for A and B lighting situation roads

Figs. 28 + 29

Post-top luminaires, a preferred option for D and E lighting situation roads as well as for parks and gardens

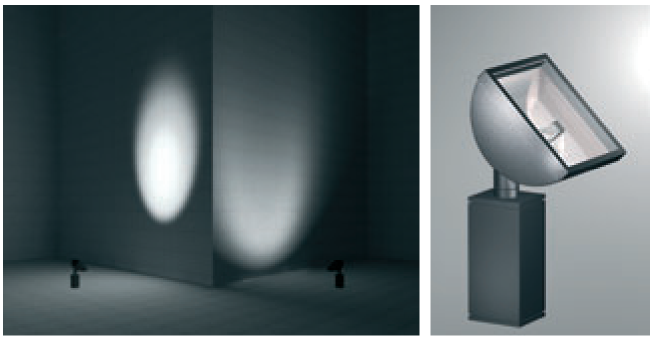
Figs. 34 + 35

Secondary luminaires (also: indirect luminaires), a preferred option for D and E lighting situation roads as well as for parks and gardens



Figs. 36 + 37

Bollard luminaires, (left) for paths in parks and gardens and light stelae (right), a preferred option for D and E lighting situation roads as well as for parks and gardens



Figs. 42 + 43

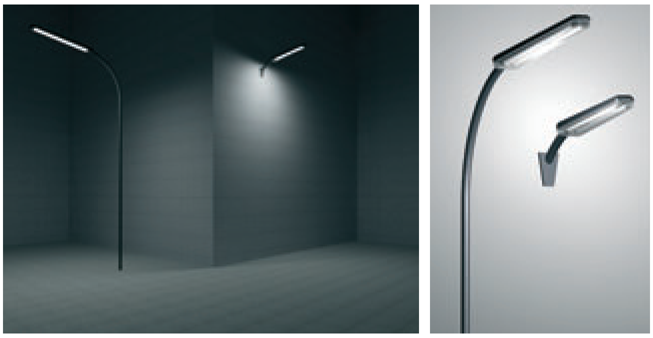
Projector luminaires for spot- (left) and floodlighting (right).

Figs. 44 + 45

Large-area luminaire, used e.g. for outdoor car park lighting

Figs. 22 + 23

Side-entry luminaires, a preferred option for A and B lighting situation roads



Figs. 24 + 25

Post-top luminaire (left) with fluorescent lamps, a preferred option for A and B lighting situation roads, and as wall luminaire (right) e.g. for paths

Figs. 30 + 31

Decorative column luminaires, a preferred option for D and E lighting situation roads as well as for parks and gardens

Figs. 32 + 33

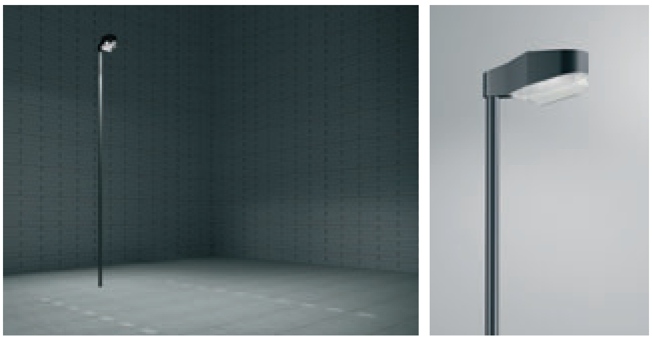
Path luminaires, a preferred option for D and E lighting situation roads as well as for parks and gardens

Figs. 38 + 39

Recessed ground luminaires (left) for object illumination and accentuating lighting as well as orientation luminaires (right) as recessed wall lights

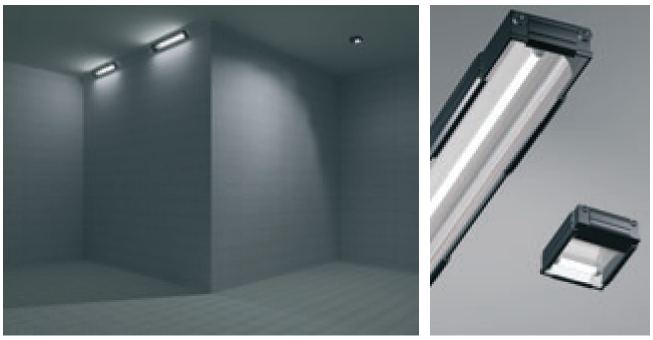
Figs. 40 + 41

Small floods and spots for object illumination; the spot on the right integrates well in facades



Figs. 46 + 47

Luminaire with light distribution specially designed for pedestrian crossings



Figs. 48 + 49

Tunnel luminaires for fluorescent lamps (left) with symmetrical light distribution curve and for high-pressure sodium vapour lamps (right) with asymmetrical light distribution curve, both designed to afford a higher degree of protection

Standards and literature

DIN 13201 Road lighting - Part 1: Selection of lighting classes

DIN EN 13201 Road lighting
Part 2: Performance requirements
Part 3: Calculation of performance
Part 4: Methods of measuring lighting performance

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

DIN 5340 Terms for physiological optics

DIN 67523 Lighting of pedestrian crossings (sign 293 StVO) with additional lighting
Part 1: General characteristics and guide values
Part 2: Calculation and measurement

R-FGÜ 2001 – Richtlinien für die Anlage und Ausstattung von Fußgängerüberwegen, published in Verkehrsblatt (VkBl) 2001, page 474 (www.verkehrsblatt.de)

DIN 67524 Lighting of street-tunnels and underpasses
Part 1: General requirements and recommendations
Part 2: Calculation and measurement

Guide for lighting of road tunnels and underpasses, CIE publication 88 (2nd edition), Vienna 204 (www.cie.co.at/cie)

RABT – Richtlinie für die Ausstattung und den Betrieb von Straßentunneln, Cologne 2006, published by Forschungsgesellschaft für Straßen- und Verkehrswesen e.V. (FGSV) as title 339 (www.fgsv-verlag.de)

Zu Konfliktzonen: Allgemeines Rundschreiben für den Straßenbau 23/98 des Bundesverkehrsministeriums

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

Straßenbeleuchtung und Sicherheit, publication no. 17:1998, Deutsche Lichttechnische Gesellschaft (LiTG) e.V., Berlin 1998 (www.litg.de)

Messung und Beurteilung von Lichtimmissionen künstlicher Lichtquellen, publication no. 12.2:1996, Deutsche Lichttechnische Gesellschaft (LiTG) e.V., Berlin 1996 (www.litg.de)

Hinweise zur Messung und Beurteilung von Lichtimmissionen, Beschluss des Länderausschusses für Immissionsschutz (LAI) resolution of 10 May 2000 (www.lai-immissionsschutz.de)

Zur Einwirkung von Außenbeleuchtungsanlagen auf nachtaktive Insekten, publication no. 15:1997, Deutsche Lichttechnische Gesellschaft (LiTG) e.V., Berlin 1997 (www.litg.de)

DIN 13201-1 or DIN EN 13201?

Readers who are not concerned with road lighting on a daily basis may be puzzled by references in this booklet to “DIN 13201 Part 1” or “DIN 13201-1”. Surely there should be an “EN” in the title – the acronym for European norm. After all, it is present in all references to parts 2–4 of the European road lighting standard.

But the omission is not a printing error. Part 1 of the standard has only nationwide and not EU-wide application because the member states of the European Union have been unable to agree on a common Part 1. The quest for compromise ended without consensus: only half of the EU members would have accepted Part 1. Parts 2–4 passed the final hurdle of the harmonisation process but Part 1 was not even put to the vote.

Now, the road lighting standard lacks a Part 1 in many countries, where old national standards still (partially) apply. Not so in Germany, where Part 1 of the new standard does apply. In the meantime, Austria and Czech Republic have followed Germany’s example and also put the national standard into force.

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Photo 71: Strasse des 17. Juni in Berlin.

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3

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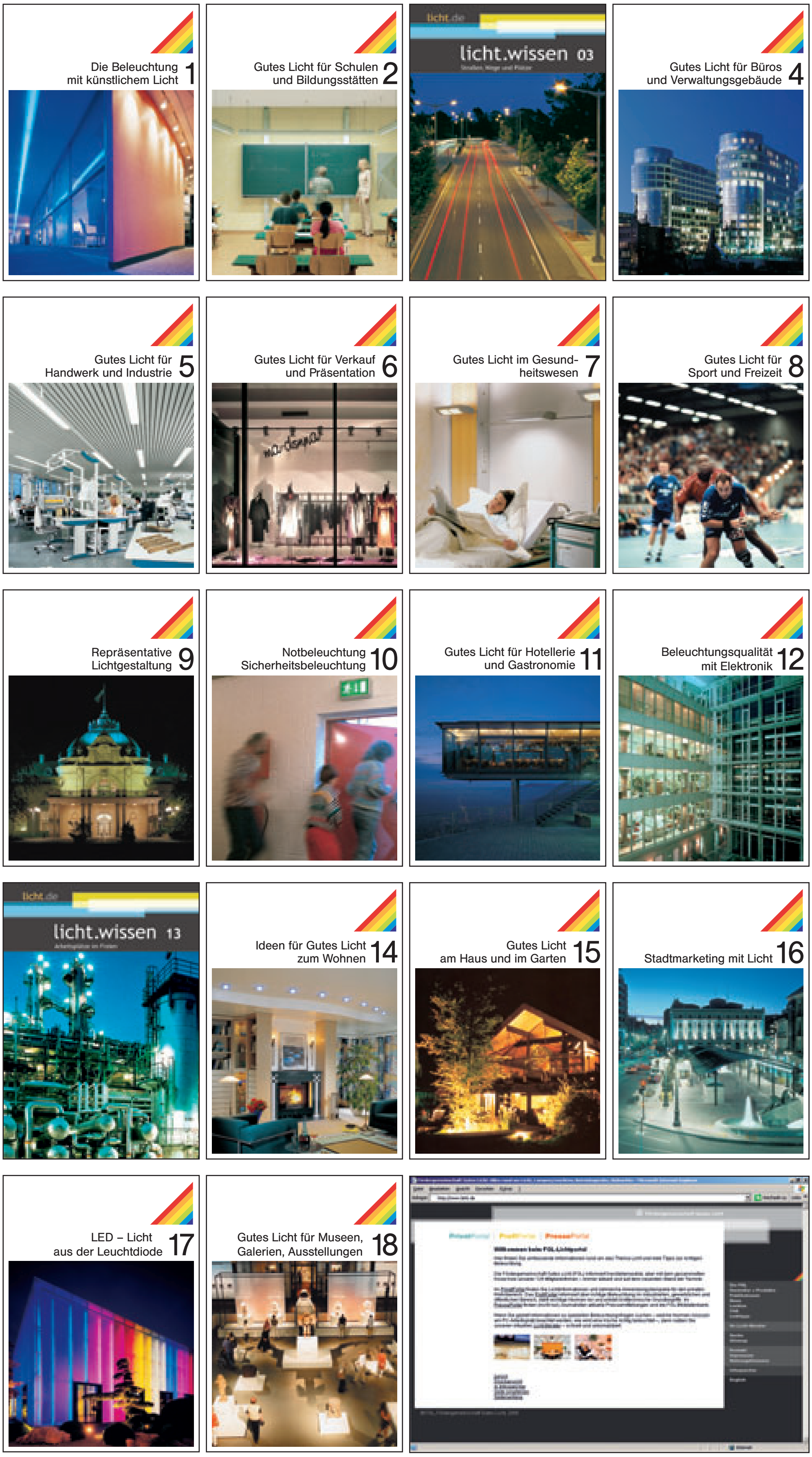
On the Internet, Fördergemeinschaft Gutes Licht offers tips on correct lighting for a variety of domestic and commercial "Lighting Applications". In a Private Portal and a Pro Portal at www.all-about-light.org, numerous examples of applications are presented. Explanations of technical terms are also available at the click of a mouse on the buttons "About Light" and "Lighting Technology". Databases containing a wealth of product data, a product/supplier matrix and the addresses of the members provide a direct route to manufacturers. "Publications" in an online shop and "Links" for further information round off the broad spectrum of the Fördergemeinschaft Gutes Licht light portal.



The new booklet 13 will shortly be available in English as a pdf file (free download at www.licht.de); booklet 15 is out of print.

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