Fördergemeinschaft Gutes Licht

Good Lighting for Safety on Roads, Paths and Squares 3

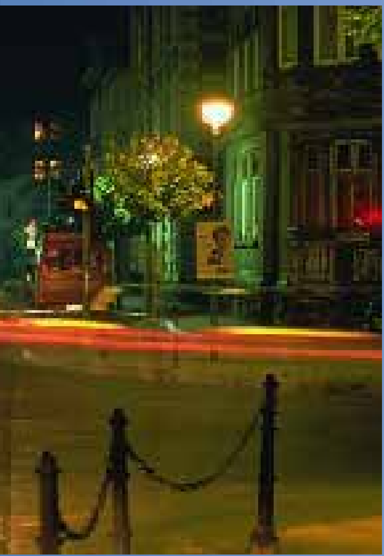
Contents

In 1997, 3,834 of 8,549 roads deaths in Germany occurred on quiet roads at night; 34.9 percent of the road users who were seriously injured were involved in accidents at twilight or after dark.

1

Good street lighting improves visual performance and reduces accidents by an average of 30 percent.

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



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With a connected load of 13 W per person, the electricity consumed by street lighting works out at less than 50 kWh a person a year.

Street lighting costs DM 20 per person a year, only DM 7 of which is for electricity.

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Street lighting and safety

Accidents at night: 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: nearly 50 percent of fatal accidents occur during the hours of darkness, although night-time motoring accounts for only 25 percent of all kilometres driven. That is one of the findings of a 1993 study by the International Lighting Commission CIE (Commission Internationale de L'Eclairage) conducted in 13 members states of the Organization for Economic Co-operation and Developemnt (OECD).

In 1997 in Germany, the number of road deaths fell by 2.8 percent to 8,549 – the lowest level since records began in 1953.

However, accidents during the hours of darkness (twilight and at night) claimed 3,834 of those lives (44.8 %) and were responsible for 34.9 percent 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,

Street lighting enhances road safety and guards against crime
We rely on our eyes for more than 80 percent 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. Street 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.

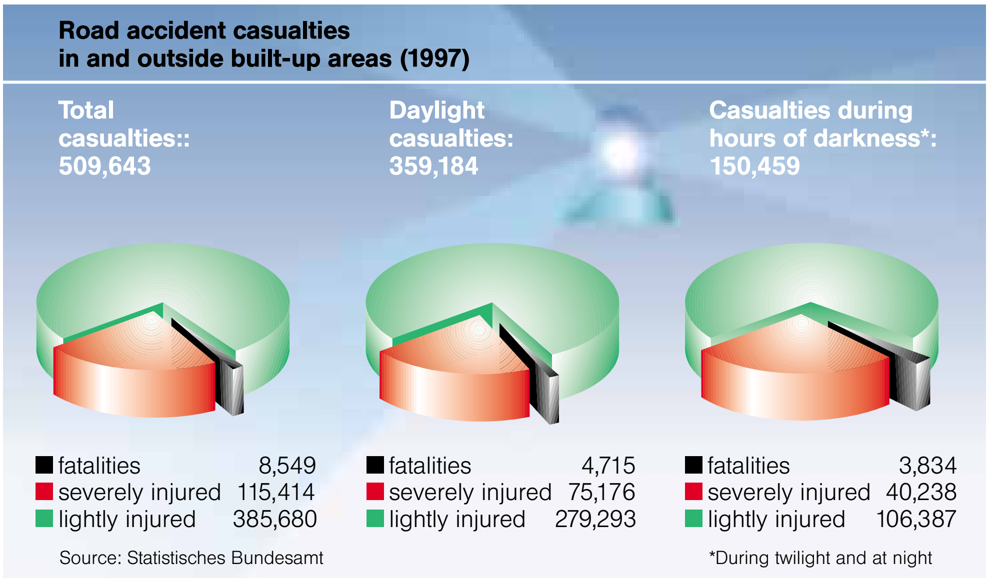
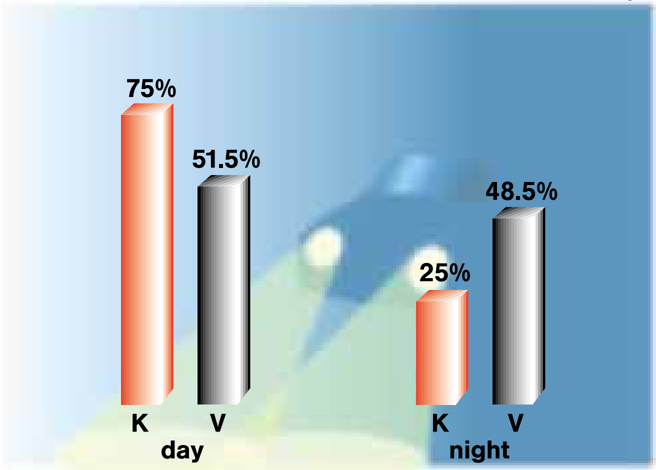


Fig. 7



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

Fig. 8

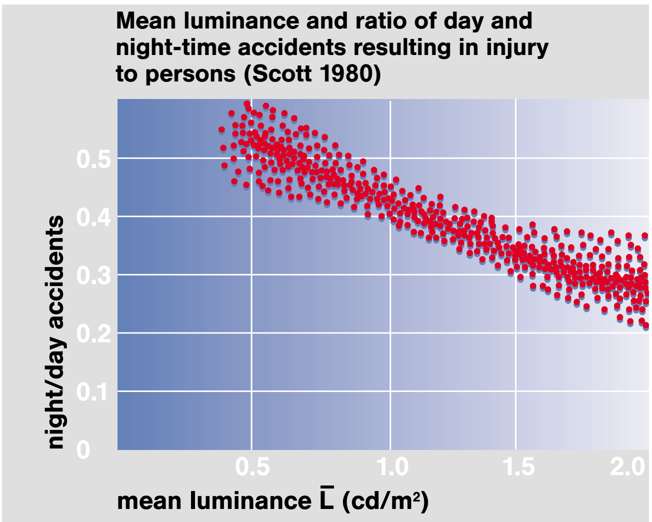


Fig. 9

Because good street lighting is an aid to visual performance, it cuts the number of traffic accidents by an average of 30 percent.

Raising luminance from 0.5 to 2 cd/m² reduces the night/day accident ratio from 50 to 30 percent.

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 vision is impaired by glare.

More light, fewer accidents
Good street lighting improves visual performance and considerably reduces the number of accidents – by 30 percent overall and by 45 percent on country roads and at crossroads and other danger points. This was shown by another 1993 CIE study, based on every study available worldwide on the connection between accidents and street lighting.

Doubling the average roadway luminance significantly reduces the number of night-time accidents. 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 percent. The number of accidents involving pedestrians and cyclists dropped by 68 percent and the number of casualties fell by 45 percent.

10

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 them being identified and potential victims are insecure and more vulnerable.

Higher horizontal illuminance – together with high vertical illuminance where the presence of pedestrians is pronounced (see "Identifying faces at a distance" – 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.

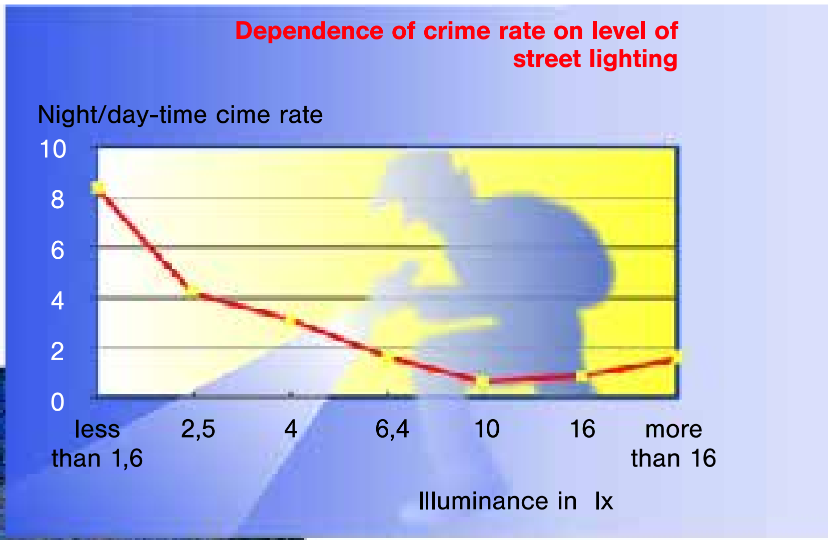


Fig. 11

Numerous studies have shown that increased illuminance produces a sharp decrease in night crime (see Figure 11). They also confirm that a higher lighting level gives residents a greater sense of security, which makes for a better neigbourhood and a better quality of life.

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

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

- street lighting is not expensive,
- refurbishment costs are soon recouped and pave the way for future economies.

Costs
Total street 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 1997, a total of 108,072 accidents were registered in Germany during the hours of darkness (compared with 272,763 in daylight). 45,165 were classed as serious accidents (as against 64,224 in daylight). Altogether, the 380,835 accidents in which people were hurt caused economic damage estimated at DM 25 billion.

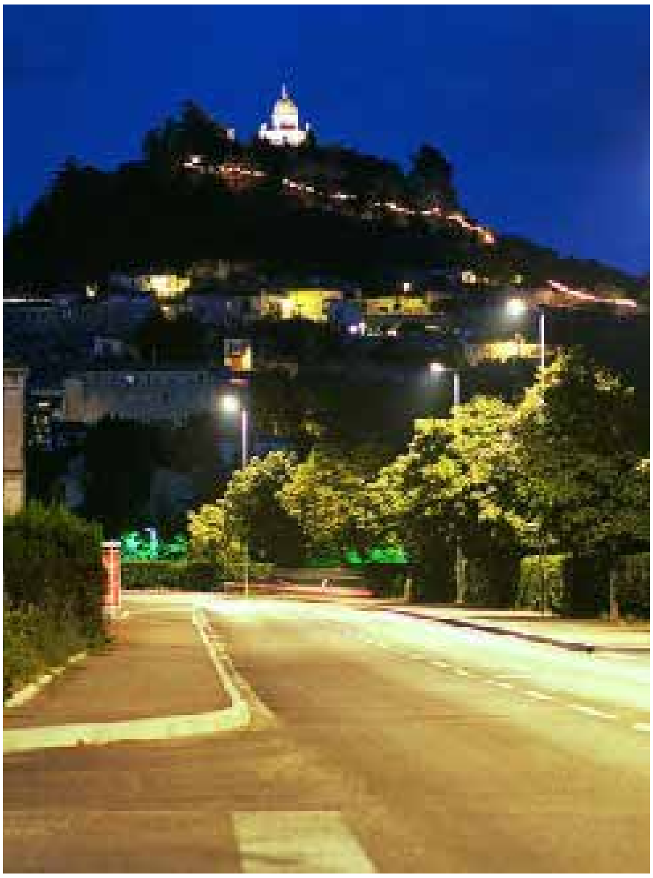
Energy consumption and operating cost of street lighting in Germany (old federal states)

Percentage of total primary energy consumed by street lighting	approx. 0.1 %
Percentage of total electricity consumed by street lighting	approx. 0.7 %
Electricity consumption per person	approx. 50 kWh/year
Connected load of street lighting	approx. 700 Megawatts
Connected load per person	approx. 13W
Total operating cost of street lighting	approx. DM 1.1 bn/year
Total operating cost per person	approx. DM 20/year
Total cost of electricity for street lighting	approx. DM 400 million/year
Cost of electricity for street lighting per person	approx. DM 7/year
Average percentage of local government expenditures attributable to electricity for street lighting	approx. 0.4 %

Source: VDEW

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, 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 5044. 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.



The amount and total cost of energy consumed by street lighting are often overestimated. 12

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, street lighting consumes comparatively little energy and thus offers limited scope for conservation (see Figure 13, page 6).

Public street lighting in Germany – in its entirety – accounts for only
• 0.1 percent of all the energy consumed and
• 0.7 percent of the electricity consumed nationwide each year.

The connected load of street lighting in Germany works out at 13 W per person, which means per capita consumption is just 50kWh a year.

Low energy costs
The electricity bill for street lighting amounts to just DM 7 per person a year. Street lighting power costs make up an average of 0.4 percent of local authority expenditures.

Other operating costs add another DM 13, which raises the total annual cost of operating street lighting to DM 20 a person.

Refurbishment lowers costs
In some places, electricity costs are unusually high. This is almost always due to ageing lighting systems, i.e. systems which are 20, 25 or even 30 years old. The only remedy is refurbishment: complete renewal or conversion
• to long-life lamps with high luminous efficacy,
• to cost-efficient luminaires with optimised optical control systems and
• to energy-saving electrical components 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 through energy savings; it also lowers all other operating costs:
• Long-life luminants save 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.

A practical example showing that refurbishment pays off
Along a 2.5-kilometre stretch of road with a central reservation, 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 40 percent reduction in energy consumption cuts the electricity bill by DM 27,830 a year. After a payback time of just 2.7 years, this money has a direct positive impact on accounts.

System comparison	Old system	New system
Investment costs	–	75,372 DM
Lamping	**(a)**	**(b)**
Lamp wattage	400 W	150 W
Luminaire wattage	425 W	170 W
Luminous flux	22,000 lm	17,000 lm
Connected load	52.66 kW	21.1 kW
Annual operating hours	4,000 hrs.	4,000 hrs
Annual consumption	210,640 kWh	84,400 kWh
Annual electricity costs	DM 46,828	DM 18,998
Annual saving	**–**	**126,240 kWh**
	–	**DM 27,830**

Energy consumption relatively low
From an environmental angle, one of the most important points to consider about street lighting is how much energy it consumes. The answer is: relatively little (see Figure 13). Nevertheless, even street lighting has become more energy-efficient: in recent years, it has decreased its share of the electricity used for lighting (excluding private households) by 1.5 percent to 6.2 percent – thanks to energy-saving lamps and more efficient lighting technology incorporated in new and refurbished lighting systems.

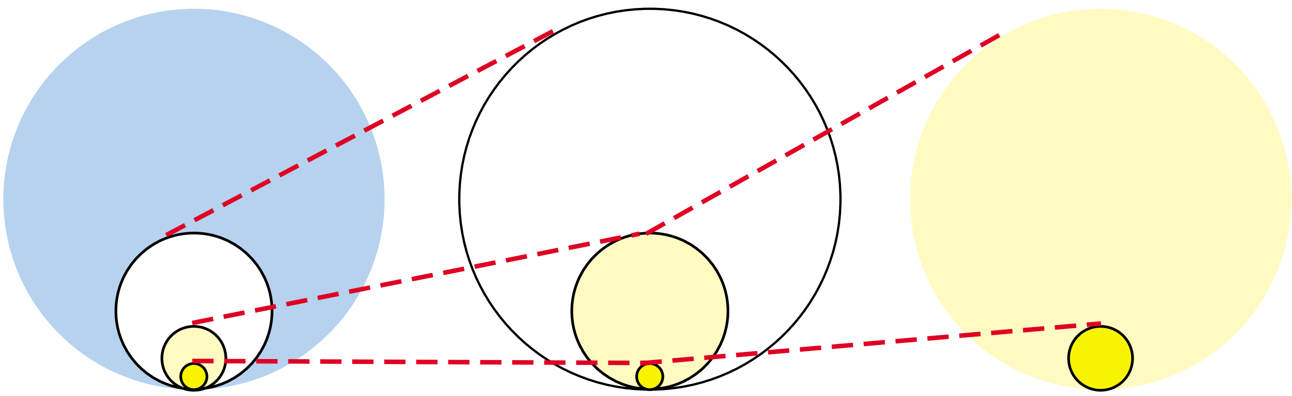
Conserving energy systematically

Minimising street lighting power consumption calls for energy-efficient lighting systems. These consist of
• long-life lamps with high luminous efficacy, measured in lumens (lm) per Watt (W): the higher the ratio lm/W, the more light generated by the energy consumed and the better the energy balance of the lamp.
• efficient luminaires (high light output ratio) with optical controllers directing the light generated onto the surface where illumination is needed,
• electrical components with low power loss ratings.

Connected load reduced: power consumption cut by 47 percent

Systems compared	Old system	New system
Luminaire	mushroom luminaire with opal enclosure	post-top luminaire with optical control system
Lamping	high-pressure mercury vapour lamps	compact fluorescent lamps
Lamp wattage per luminaire	80 W	2 x 18 W
Luminaire wattage	89 W	48 W
Connected load per km	3 kW	1.6 kW
Saving per kilometer	**–**	**1.4 kW**

Energy balance on the road
Another comparison underlining street 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 street lighting accounted for just 1.5 percent of the energy consumed; the other 98.5 percent 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 street lighting would still account for less than three percent of the total.



total energy consumption	*= 100 %*
percentage as electricity	*17.39 %*
percentage for lighting	*1.9 %*
percentage for street lighting	*0.1 %*

electricity consumption	*= 100 %*
percentage for lighting	*10.8 %*
percentage for street lighting	*0.7 %*

electricity consumption for lighting	*= 100 %*
percentage for street lighting	*6.2 %*

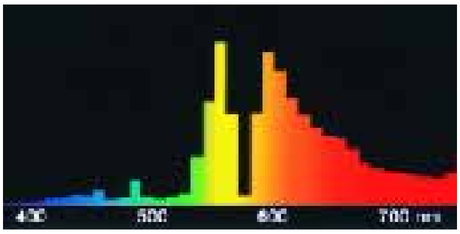
Fig. 13

Low energy consumption: In Germany, the electrical energy used for street lighting accounts for only 0.1 percent of total annual energy consumption (diagram not to scale, based on 1993 figures).

Recycling lamps

Lamps contain minute quantities of mercury, so under Germany's Commercial and Industrial Waste Management Act, most discharge lamps need to be treated as special waste. Lamp recyclers in the AGLV working group (Arbeitsgemeinschaft Lampenverwertung) have created a nationwide collection and recycling system in compliance with strict certification criteria, thus ensuring that raw materials are recovered and re-used.

AGLV members include members of the Electrical Lamp Manufacturers Association in the Zentralverband Elektrotechnik- und Elektronikindustrie (ZVEI) e.V. (for information available from the ZVEI, see page 34). These companies place their expertise at the recyclers' disposal and advise them of the waste management requirements of materials contained in new lamps. One of the primary objectives of the AGLV is to raise the return rate of used lamps.



Spectral radiance distribution of a high-pressure sodium vapour lamp 14

Avoiding light pollution

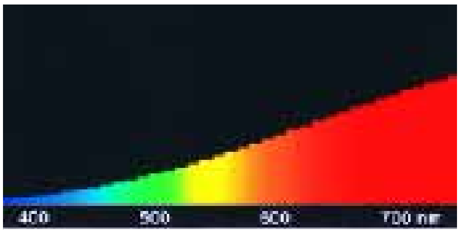
Where residents are bothered by light from streetlamps shining into their homes, they have a right to complain – a right enshrined in Germany in the Federal Ambient Pollution Control Act. So any risk of "light pollution" needs to be eliminated at the planning stage.

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 Literature, page 34) 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" and recommends that they should be applied by environmental protection agencies.

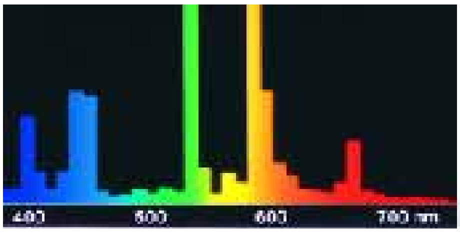
Light and insects

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

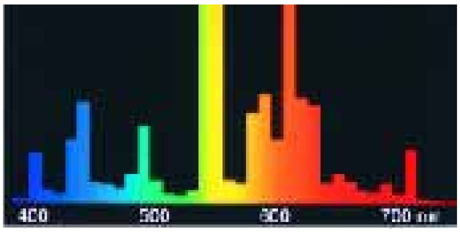
Light with a predominantly yellow/orange spectral content is not so attractive to insects because their eyes have a different spectral sensitivity from the human eye. They respond more sensitively to the spectral composition of the light from fluorescent lamps, high-pressure mercury vapour lamps and metal halide 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 Literature, Page 34).



Spectral radiance distribution of a general service tungsten filament lamp 15



Spectral radiance distribution of a metal halide lamp 16



Spectral radiance distribution of a warm-white fluorescent lamp 17

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

Daylight illuminance ranges from 5,000 to 100,000 lux. On a moonlit night, 1 lux is about the maximum. The fact that we can "see" over this vast brightness range is due to the eye's ability to adapt. In some adaptation zones, 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 activated: colours are easily distinguished, objects and details clearly made out. In darkness, different receptors are active: rods, which are fairly insensitive to colour but highly sensitive to brightness. In the transitional stage of 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. Where surroundings are darker, an object needs either to contrast more sharply or be larger in order to be perceived.

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 10/11).

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.

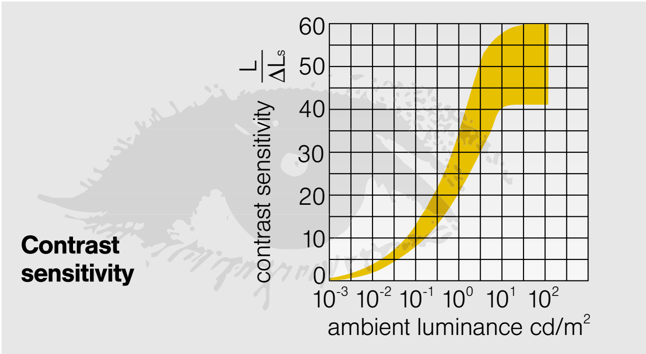


Fig. 18

In daylight, visual performance is at its peak: the eye's colour-sensitive cone receptors are active, everything is precisely and vividly discernible "in colour". 19

Daylight: Optimum visual performance, good colour discrimination, objects, details and spacial relationships can be clearly made out. 20

Street lighting: Shapes and colours are much harder to make out but can still be adequately distinguished. 21

Moonlight: No colour perception, low-contrast details are no longer discernible. 22

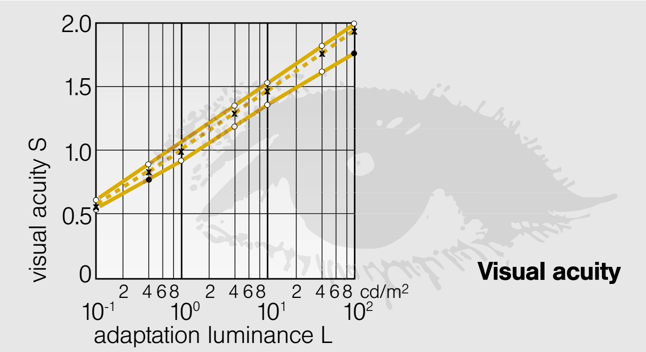


Fig. 23

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, for example, has much less time for this than a pedestrian.

Adaptation time
It takes time for the eye to adapt to different brightnesses. The adaptative process and hence 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 faster unimpaired visual performance can be achieved.

Visual disturbance occurs when our eyes don't have enough 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.

As darkness increases, visual performance deteriorates. Street lighting restores lost performance, enabling shapes and colours to be adquately made out. 24

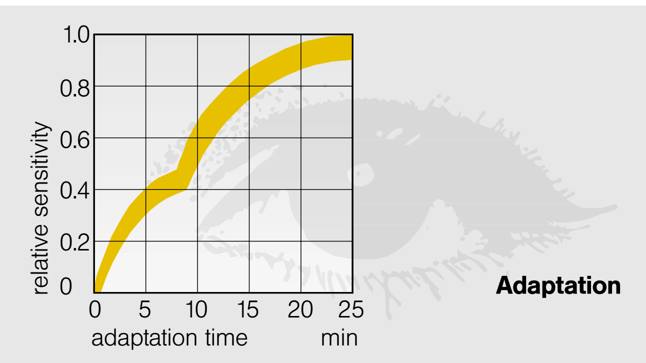


Fig. 25

Luminous flux 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 is the amount of luminous flux radiating in a particular direction. It is measured in candela (cd). The way luminous intensity is distributed in the room – normally depicted by an intensity distribution curve (IDC) – defines the shape of the beam of a luminaire or reflector lamp.

Luminance is the brightness of a luminous or illuminated surface as perceived by the human eye. Measured in cd/m² or cd/cm², it expresses the intensity of the light emitted or reflected by a surface per unit area.

Illuminance – 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 luminous flux, illuminance is 1 lux.

Adequate level of brightness
To enable us to see well, an adequate level of brightness (lighting level) is essential. In DIN 5044, the yardstick used to determine level of brightness is mean luminance or mean illuminance.

Illuminance (measured in lux) 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 is the key quantity for nearly all roads with motor traffic (see pages 14/15). It depends on the position of the observer, the geometry of the lighting system, the reflective properties of the road surface, the luminous flux of the lamps and the intensity distribution of the luminaires. Luminance is calculated for standard assessment fields.

Illuminance
For collector, local service and residential streets (see pages 16/17), illuminance is the yardstick used because neither clear-cut assessment fields nor a standard observer position can be defined. What is assessed is the horizontal illuminance on the roadway. Where pedestrian traffic is heavy, vertical and semi-cylindrical illuminance (see “Identifying faces at a distance”, page 11) are also used.


26

For most roads designed for automobile traffic, luminance is the definitive criterion for lighting level.


27

For collector, local service and residential streets, what counts is horizontal illuminance on the roadway.


28

The uniformity of the luminance along and across the roadway is good.


29

Switching off individual luminaires severely disrupts the longitudinal uniformity of the roadway luminance.

1.25 planning factor on installation
To ensure that all quality features are maintained for a lengthy period of time without the need for extra maintenance work, DIN 5044 recommends that a planning factor of 1.25 should be adopted on installation. Maintenance work needs to be carried out at the latest when luminance or illuminance decrease to 70 percent of this rated value.

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 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.

Uniformity of luminance is established by calculating overall uniformity U_O and longitudinal uniformity U_l, taking account of the geometry (assessment field) and reflective properties of the roadway. Overall uniformity U_O expresses 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.

Illuminance uniformity g_1 is the quotient of the lowest and mean illuminance.

Less glare – better visual performance
Glare can impair visual performance to such an extent that reliable perception and identification are impossible.

Physiological glare causes a measurable impairment of visual faculties, e.g. visual acuity. Psychological glare is discomforting and affects concentration 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. 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 ΔL_0 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_0, 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_0 to ΔL_{BL} is the measure of physiological glare. Where the luminance calculation produces high TI values, glare is intense. Glare-suppressed lighting systems take account of threshold increments between 7 and 10 percent. For relatively quiet roads, 15 to 20 percent is still an acceptable value.

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.

These two characteristics are of relatively minor importance in outdoor lighting. Even so, it is still advisable to use lamps with good colour rendering properties so that colour contrasts can be made out and information intake is maximized.

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

Identifying faces at a distance
Good lighting is essential to enable pedestrians to identify approaching figures, anticipate their intentions and react accordingly. 1 lux semi-cylindrical illuminance is a minimum requirement here. Measured at a height of 1.5 metres above the ground, semi-cylindrical illuminance describes the amount of vertical illuminance that falls on a semi-cylindrical surface.

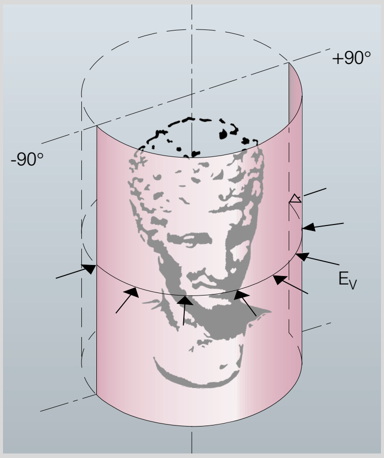
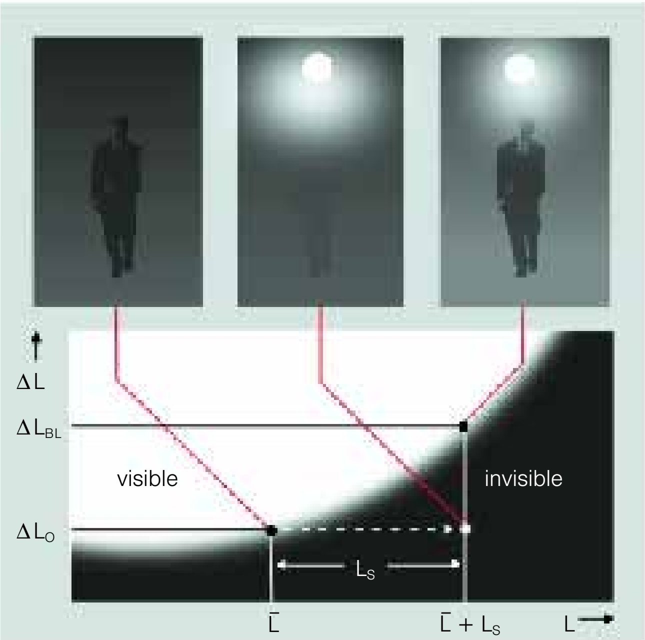


Fig. 30



Where glare occurs, luminance contrast must be raised to ΔL_{BL} in order to make the visual object discernible.
Fig. 31

Requirements defined by risk potential
The greater the risk of accident during the hours of darkness, the more light a street lighting system needs to provide. Where traffic volumes at night 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 connected with this is the safety of the road itself, which depends on its size, its position and the speed limit that applies.

DIN 5044 criteria
In defining risk potential, DIN 5044 makes a distinction between traffic and structural criteria:

Traffic criteria
• Roads with or without oncoming traffic (with or without central reservation).
• Average traffic volume at night.
• Excess periods (number of hours a year in which average traffic load is exceeded)

Structural criteria
• Cross-sectional design of road and form of traffic control.
• Segregation of different types of road user.
• Road within or outside built-up area.
• Built-up or non-accessed street.
• Road with or without stationary vehicles on/alongside carriageway.
• Speed limit.

Non-accessed urban road with no stationary vehicles, infrequent disruption: medium lighting requirements during peak traffic hours (left), low requirements when traffic is light.

Built-up street with stationary vehicles on or alongside the carriageway, moderate to frequent disruption: lighting requirements rise as traffic volume increases (left).

Collector, local service and residential street with mixed traffic, frequent disruption: lighting requirements rise in line with traffic volume (left).

32

33

34

Basis for planning: Roadway luminance for streets in built-up areas (DIN 5044 guide values)

Cross-section of road	with central reservation				without central reservation				
in motor vehicles/(h x lanes) with Excess period in h/a	900 ≥200	600 ≥300	200 ≥300	200 <300	600 ≥200	300 ≥300	100 ≥300	100 <300	<300
	L_n U_l	L_n U_l	L_n U_l	L_n U_l	L_n U_l	L_n U_l	L_n U_l	L_n U_l	L_n U_0
Urban roads									
non-accessed street, no stationary traffic	1.0 0.6	1.0 0.6	0.5 0.5	0.5 0.5	1.5 0.6	1.5 0.6	1.0 0.6	0.5 0.4	0.3 0.3
built-up, no stationary traffic on/alongside carriageway	1.5 0.6	1.5 0.6	1.0 0.6	0.5 0.5	2.0 0.7	1.5 0.6	1.0 0.6	0.5 0.4	0.3 0.3
built-up, with stationary traffic on/alongside carriageway	2.0 0.7	2.0 0.7	1.5 0.6	1.0 0.6	2.0 0.7	2.0 0.7	1.5 0.6	0.5 0.4	0.3 0.3
Kraftfahrstraßen (Road sign 331 Road Traffic Act)									
permissible speed > 70 km/h	1.5 0.6	1.0 0.6	0.6 0.5	0.5 0.6	1.5 0.6	1.0 0.6	0.5 0.6	0.5 0.6	
permissible speed ≤ 70 km/h	1.0 0.6	0.5 0.6	0.5 0.5	0.5 0.5	1.0 0.6	1.0 0.6	0.5 0.5	0.5 0.6	
Autobahnen (Road sign 330 Road Traffic Act)									
permissible speed > 110 km/h	1.0 0.7	1.0 0.7	1.0 0.7	1.0 0.7					
permissible speed ≤ 70 km/h	1.0 0.7	0.5 0.6	0.5 0.6	0.5 0.6					

L_n: nominal luminance in cd/m² U_l: longitudinal uniformity $\frac{L_{l,min}}{L_{l,max}}$ U_0: overall uniformity $L_{min}/\overline{L}$ (standard value: $U_0 \geq 0{,}4$)

Guide values for luminance
For motorways, urban roads and major roads, DIN 5044 uses luminance as the yardstick for lighting levels. The emphasis here is on illuminating the roadway. The table above shows the relevant guide values.

L_n is the nominal luminance, which is the local and temporal mean luminance of the roadway. U_l is the longitudinal uniformity, the ratio of the lowest to highest luminance in the centre of the observer's lane. U_O is the overall uniformity, the ratio of the lowest to mean luminance over the entire assessment field.

Guide values for illuminance
For collector, local service and residential streets, DIN 5044 uses illuminance as the yardstick for lighting level. It is recommended that the adjacent building façades should be lit as well as the entire traffic area. Apart from horizontal illuminance and uniformity, semi-cylindrical illuminance also needs to be considered (see "Identifying faces at a distance", page 11) to take account of vertical illuminance as well.

The level of lighting provided for pedestrian precincts, squares and park paths should be at least as high as for local service roads. Where pedestrian volumes are at times high, up to 10 lx illuminance is recommended.

Basis for planning: Illuminance

Traffic-calmed zones (DIN 5044 guide values)		
Streets used by through traffic	E_n = 7 lx	$g_1 \geq 0.2$
Streets used by residents	E_n = 3 lx	$g_1 \geq 0.1$
Cycle paths		
in streets with lighting	$E_{min} \geq$ 3 lx	$g_2 \geq 0.15$
in streets with no lighting	$E_{min} \geq$ 3 lx	$g_2 \geq 0.3$
at least 8 m away from streets with no stationary street lighting:	$E_{min} \geq$ 1.5 lx	$g_2 \geq 0.15$
Pedestrian zones		
Pedestrian precincts	E_n = 5 lx	$g_2 \geq 0.08$
Squares	E_n = 5 lx	$g_2 \geq 0.1$
Squares, high density use	E_n = 10 lx	$g_2 \geq 0.1$
Flat footpaths	$E_{min} \geq$ 1 lx	
Footpaths with steps	$E_{min} \geq$ 5 lx	
Outdoor staircases	E_n = 15 lx	$g_2 \geq 0.3$
Underpasses	E_n = 60 lx	$g_2 \geq 0.3$

E_n: nominal illuminance in Lux (lx) $g_1 = E_{min}/\overline{E}$
$\overline{E}$: mean illuminance in Lux (lx) $g_2 = E_{min}/E_{max}$
E_{min}: minimum illuminance in Lux (lx)

For better perception
Street lighting which conforms to DIN 5044 is designed to improve road users' perception of
- the surface, course and boundaries of the roadway,
- junctions and intersections,
- obstructions,
- the position and movements of other road users
- and to prevent disruption of traffic.

Lighting requirements
On thoroughfares, visual conditions need to be tuned to the needs of the motorist, who has to be able to identify and judge the course of the road, the state and boundaries of the carriageway, traffic signs, other vehicles and road users as well as obstacles on the carriageway 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 only visible 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, making objects stand out visually from their surroundings (roadway) is one of the primary functions street lighting needs to perform.

The arrangement of luminaires in a street lighting system provides visual guidance. Special hazard zones, such as junctions, crossroads or pedestrian crossings (see page 19), are identified earlier if they are furnished with supplementary lighting and, if necessary, distinguished by a different light colour from that of the adjacent street lamps.

Where street lighting ends or drops to a lower lighting level, the decrease in luminance should be gradual. This makes it easier for the eye to adapt to the darker conditions, which takes longer than adapting from dark to light.

The course of the road, the carriageway and its boundaries, traffic signs and hazards on and at the side of the road are clearly identifiable. 35

Hazard zones on a road are highlighted by supplementary lighting – here provided by the luminaire in the background on the right. 36

At crossroads, supplementary lighting heightens road safety. 37

A link road between two villages with lighting designed to DIN 5044 specifications. 39

Assessment criteria
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.

On the bend, luminaires are not positioned on the central reservation. Closer luminaire spacing in the middle of the bend makes for a better "guide-rail" effect. 38

Standard definitions, classifications and methods for calculating all these factors are contained in DIN 5044 and other relevant industrial standards. There are also calculation tables and computer software available for street lighting planning.

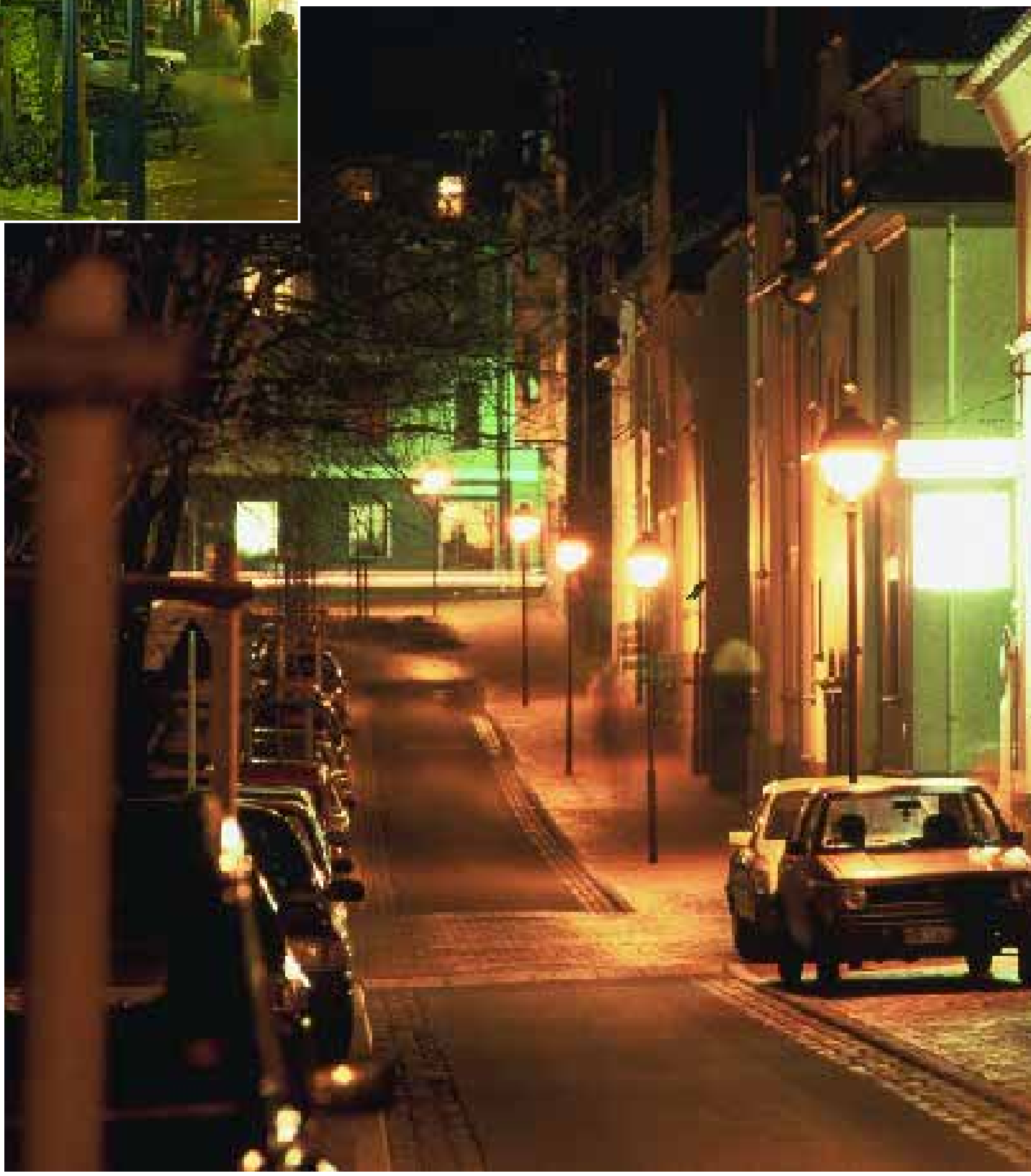
Minimum values for mean roadway luminance are between 0.3 and 2 cd/m^2 (see page 13). Other variables which have an important bearing on street lighting quality are longitudinal and overall uniformity (see page 10) and glare limitation, which needs to be adequate and to take account of admissible threshold increments (see page 11).

Collector, local service and residential streets

40

Good for road safety and good-looking as well: lighting and luminaires help make a shopping street more attractive after dark.

Assessment criteria
Lighting criteria here are mean horizontal illuminance – 3 lx for low traffic loads (local service street), 7 lx for heavier traffic (collector street, see also page 13) – and its uniformity.



Lighting requirements
Collector, local service and residential streets need to cater to a variety of road users. Given this mix of slow-moving and parked motor vehicles and the frequent presence of cyclists and pedestrians, one of the primary requirements lighting has to meet is the need to reduce the risk of accident, especially for the "weaker" road users.

Another, equally important task is crime prevention: higher illuminance makes for better perception and identification and thus acts as a deterrent for would-be assailants and thieves (see page 3).

Apart from performing actual lighting functions, luminaires in traffic-calmed zones are an element of urban design: they help shape the face of a street and contribute significantly to a better residential environment. Even the light they distribute makes an aesthetic impact: its warm colour appearance creates a "homely" atmosphere.

Urban architecture: luminaires lend character and create a "homely" atmosphere.

A typical residential street for mixed traffic.

42

This is because traffic-calming installations and multi-textured road surfaces make luminance an unsuitable criterion for assessing residential street lighting. Lighting quality is further enhanced by taking account of vertical illuminance, assessed by the semi-cylindrical illuminance method (see “Identifying faces at a distance”, page 11). This makes it easier to identify approaching figures, permits a prompter response to a perceived threat and thus provides a safeguard against criminal assault.

Collector, local service and residential street lighting needs to illuminate more than just the roadway. It should also provide adequate, uniform illuminance for adjacent areas such as cycle paths, footpaths and building façades. Care must be taken here to avoid “light pollution” due to excessively high illuminance near windows (see page 7).

To avoid glare, the luminous intensity of luminaires at certain beam angles should be reduced.

41

Collector streets have high lighting requirements; illuminance is the key lighting quantity. 43

Quality lighting even where nothing moves faster than walking pace: globe luminaires in a traffic-calmed street. 44

Adequate illuminance is also important for areas flanking the roadway. 45

Lighting system geometry

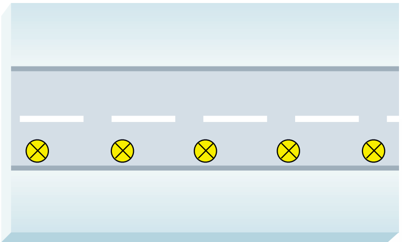


Fig. 46

One-sided arrangement.

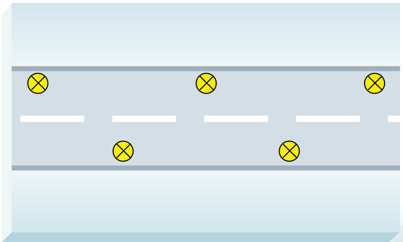


Fig. 47

Two-sided facing arrangement.

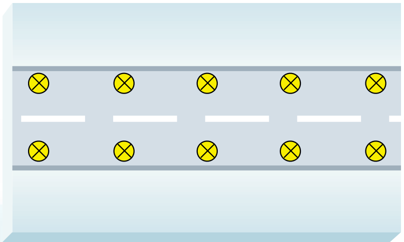


Fig. 48

Two-sided staggered arrangement.

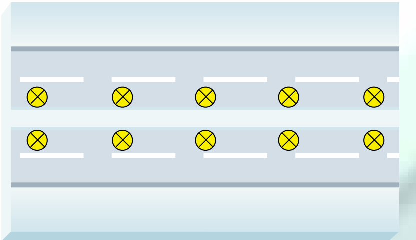


Fig. 49

Double-row arrangement over central reservation.

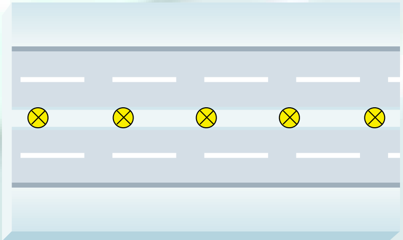


Fig. 50

Single-row arrangement over central reservation.

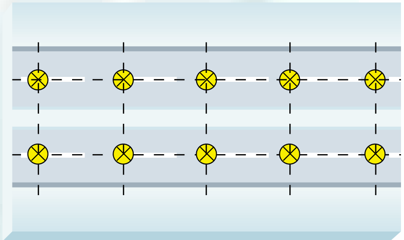


Fig. 51

Double-row parallel suspended arrangement.

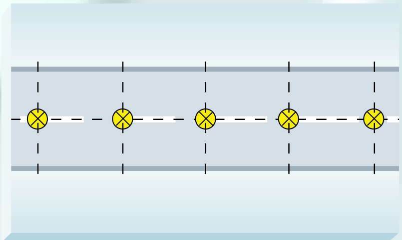


Fig. 52

Single-row suspended arrangement over the centre of the roadway.

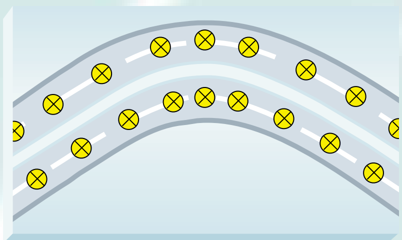


Fig. 53

Double-row arrangement on bends: closer luminaire spacing in the middle of the bend makes for a better "guidance" effect.

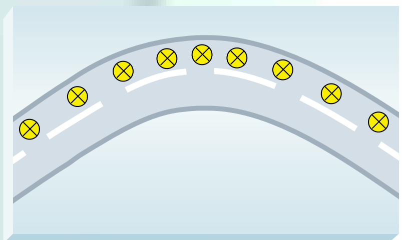


Fig. 54

Single-row arrangement on bends: closer luminaire spacing in the middle of the bend and positioning on the outside of the bend makes for a better "guidance" effect.

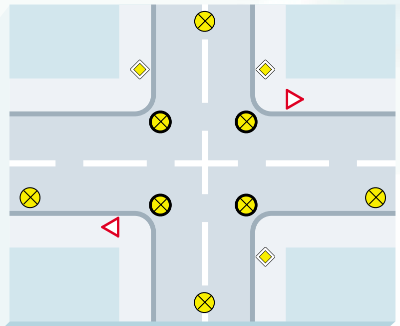


Fig. 55

Crossroads and junctions: additional luminaires highlight hazard zones.

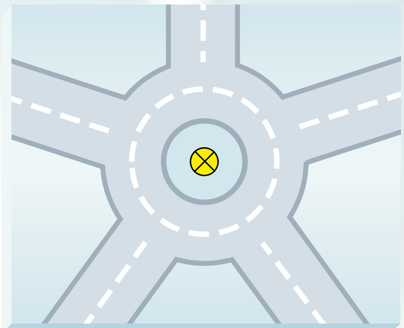


Fig. 56

Roundabout: central tall column.

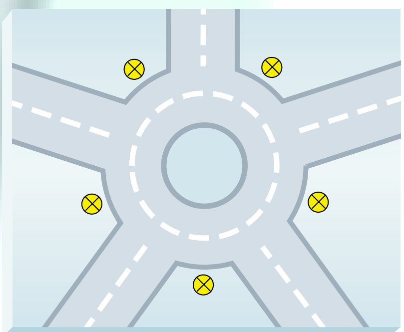


Fig. 57

Roundabout: positioning at entries and exits.

Cycle paths

Lighting requirements
More and more cycle paths are being created – but in built-up areas at least, cyclists' freedom to travel in a lane of their own is still sometimes restricted: either the cycle path borders directly on the footpath or cycle path and footpath are one, used jointly by cyclists and pedestrians. Correct lighting permits prompt identification of other path users 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 cycle paths in parks and gardens, set back from main roads or outside built-up areas, separate lighting is required. Here, special attention should be paid to uniformity of lighting because visual performance is severely impaired by patches of darkness.

Assessment criteria
The"Pedestrian Zone Lighting Guidelines" published by the Cologne-based traffic research institute "Forschungsgsellschaft für Straßen- und Verkehrswesen" apply also to cycle paths and call for 1.5 to 3 lx horizontal illuminance along the cycle path axis (see Page 13) and good uniformity. Luminaires with reflectors for extremely wide-angled intensity distribution are particularly suitable. They provide uniform lighting while permitting relatively wide – and therefore economical – luminaire spacing.

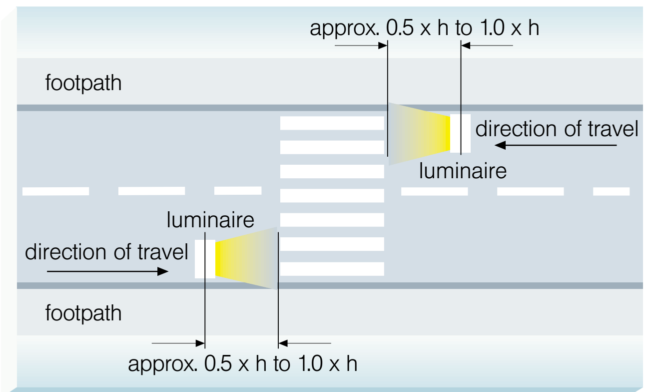
Where no light from street lighting is available, cycle paths require a separate lighting system. 58

Pedestrian crossings

Lighting requirements
Even a young child knows that the only relatively safe place to cross a road is at a light-controlled pedestrian crossing. And to make sure it stays safe after dark, a pedestrian crossing should have separate lighting. Light with a colour appearance different from that of the general street lighting has an additional signal effect.

Even where a zebra crossing is controlled by traffic lights, supplementary lighting is recommended for pedestrian safety. 59

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 zebra 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. 60).



Illuminating pedestrians from the side in the direction of travel (positive contrast); "h" is the mounting height of the luminaire. Fig. 60

Assessment criteria
The requirements for supplementary lighting for pedestrian crossings are set out in DIN 67523, Part 1. The mean vertical illuminance required for achieving positive contrast on a road lit to DIN 5044 specifications is 40 lux in the direction of travel over the central axis of the crossing. In addition, illuminance should be no less than 5 lx at any point within the supplementary lighting zone.

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 very limited. These requirements are met only by special optical control systems incorporated into pedestrian crossing luminaires.

A pedestrian precinct with atmosphere: light and luminaires dominate the scene, making it more attractive and exciting. At the same time, the light makes pedestrians feel safe. The luminaires are also a decorative feature during the day. 61

Vandal-proof and impact-resistant
The right choice of luminaire guards against damage by vandals or thieves: strong, compact quality luminaires stand up well to mechanical stress. The sturdiest designs are described as - "vandal-proof". Impact-resistant plastic enclosures avoid the risk of glass being broken, for example, on easily reachable wall luminaires. However, even the toughest luminaire cannot withstand constant exposure to rough treatment.

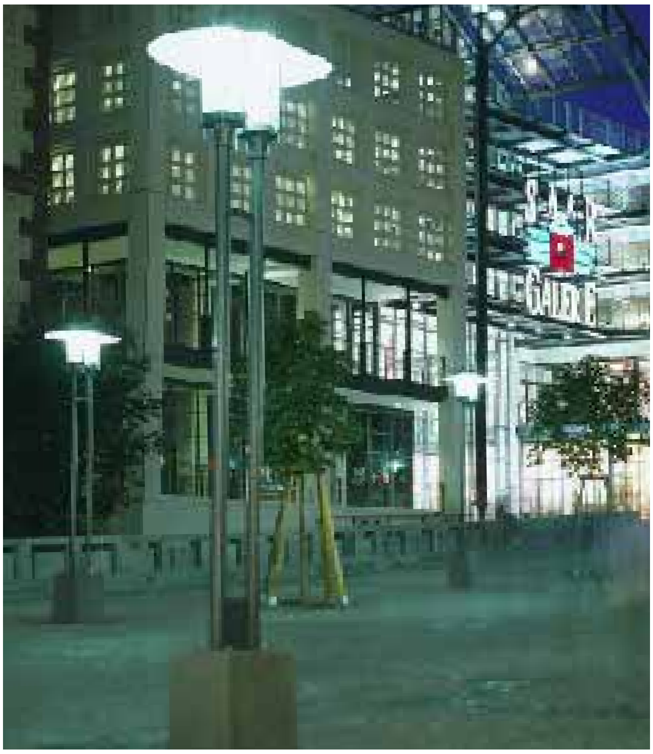
Lighting requirements
Lighting for squares and pedestrian precincts needs to meet decorative criteria. Luminaires must harmonise with the surrounding architecture and harness light to create atmosphere. However, this requirement must not be met at the expense of safety. Lighting should also help prevent 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 23).

Assessment criteria
Where only pedestrians are present, mean horizontal illuminance should be 5 lx. For malls which at times attract large numbers of shoppers,this figure should be doubled. Where pedes-

Showing the way: even in pedestrian precincts, luminaires act as "guiding lights". 62



Light and luminaires shape and structure a square. 63

trian precincts cross (traffic-calmed) streets with vehicle traffic, the requirements for pedestrian crossings (supplementary lighting, vertical illuminance up to 40 lx, see page 19) need to be met.

Taking additional account of vertical illuminance makes for better crime prevention (see "Identifying faces at a distance", page 11). It significantly improves visual perception, so potential criminals run a greater risk of being discovered and/or identified. The higher the vertical illuminance ratio, the greater the distance at which suspicious figures or movements can be spotted. At the same time, passers-by feel a greater sense of personal security.

Night scene: a new perspective created by light. 64

Discreet but decorative: when luminaires are selected, their day-time function should also be taken into account. 65

The geometry of the square is reflected by the luminaire design and arrangement. 66

Parks

Lighting requirements
The primary function of lighting in parks and other public gardens is to enhance public safety: luminaires along paths show us the way, help us get our bearings and enable us to make out the pathway surface 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
The level of path lighting required depends on ambient brightness. Mean horizontal illuminance should be more than 1 lx; where there are steps on the path or the surface is uneven, 5 lx is a minimum. Dark patches and high light-dark contrasts should be avoided: they present adaptation problems for the eye and impair visual performance.

Taking additional account of vertical illuminance significantly lowers the risk of criminal assault (see "Identifying faces at a distance", page 11). Higher vertical illuminance has a positive psychological effect: it reduces 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.

67

A decorative feature in daylight as well: the luminaires harmonize with the design of the park.

68

The lower the mounting height, the closer the spacing required between luminaires.

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 = line of vision) and there should be no risk of light from the park disturbing neighbours in their homes. (see page 7).

The luminaires show where the path goes and help park visitors get their bearings. 69

Floodlighting
Floodlighting creates decorative “night pictures”: entire buildings, building sections or façades, artworks, 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 which could disturb neighbours in their homes can be prevented by careful planning (see page 7). Installing floods at an adequate distance avoids excessively deep shadows on the object which is illuminated (see also Booklet 9 “Prestige Lighting”, page 37).

70

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 emphasize the colour character of red leaves. Metal halide lamps underline the gleam of metal and glass façades and are suitable for yellow or yellowish green as well as dark green or blue-green leaves.

The decorative path lighting highlights hazards and acts as a deterrent against crime. 71

Atmosphere and security – achieved with path luminaires alone. 72

Indoor and outdoor car parks

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

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

Assessment criteria
DIN 67528 makes distinctions between different zones in ***multi-storey car parks*** (indoor car parks). In vehicle entrance and exit zones, mean horizontal illuminance during the day should be 100 lx where adaptation conditions are favourable and 200 lx where they are not. At night, it should be 30 lx. In movement zones (roadways with mixed vehicle and pedestrian traffic) 60 lx is a minimum requirement. Parking zones require 30 lx mean horizontal illuminance, which is the level that should also be provided for all peripheral zones. The illuminance required for zones used exclusively by pedestrians – stairs, lifts, payment points – is set out in DIN 5035 “Interior lighting with artificial light”, Parts 1 and 2, and ranges between 100 and 150 lx. Rules for emergency lighting are contained in DIN 5035, Part 5, DIN VDE 0108, Parts 1 and 6 and the regulations relating to garages in the individual German states.

In the main directions of movement in movement and parking zones, adequate vertical illuminance must also be ensured: at least 10 lx semi-cylindrical illuminance (horizontal 60 lx) is needed for good 3D identification.

Other factors relevant to indoor car park lighting are uniformity of illuminance and adequate limitation of glare from luminaires and from daylight in multi-storey car parks.

73 *Good lighting from entrance to exit: brightly lit indoor car parks are safe and user-friendly.*

74 *Clear view: lighting on both sides of the movement zone also illuminates parking spaces.*

Lighting is essential everywhere in an indoor car park – also in areas used exclusively by pedestrians. The important thing here: light gives a sense of security. 75

Minimum nominal illuminance E_n required by DIN 67528

Zone	**Indoor car parks**	**Outdoor car parks heavy traffic load**	**Outdoor car parks light traffic load**
Vehicle entrances and exits	During the day:		
favourable adaptation conditions	$E_n = 100$ lx	–	–
unfavourable adaptation conditions	$E_n = 200$ lx	–	–
	At night: $E_n = 30$ lx	$E_n = 15$ lx[3)]	$E_n = 7$ lx[3)]
Movement zones	$E_n = 60$ lx[1) 2)] $g_1 \geq 0{,}4$	$E_n = 15$ lx[3)] $g_1 \geq 0{,}2$	$E_n = 7$ lx[3)] $g_1 \geq 0{,}2$
Parking zones	$E_n = 30$ lx[1) 2)] $g_1 \geq 0{,}4$	$E_n = 15$ lx[3)] $g_1 \geq 0{,}2$	$E_n = 7$ lx[3)] $g_1 \geq 0{,}2$
Peripheral zones	$E_n = 30$ lx[1)] $g_1 \geq 0{,}4$	$E_n = 15$ lx $g_1 \geq 0{,}2$	$E_n = 7$ lx $g_1 \geq 0{,}2$

1) Double for open-sided multi-storey car parks where external luminance is high.
2) At least 10 lx semi-cylindrical illuminance at any point in the principal direction of movement.
3) At least 1 lx semi-cylindrical illuminance at any point in the principal direction of movement
$g_1 = E_{min}/E$

For ***outdoor car parks***, the mean horizontal illuminance required depends on volume of traffic: DIN 67528 stipulates 15 lx minimum for car parks where mean traffic loads are heavy and 7 lx where traffic is light. Semi-cylindrical illuminance should be at least 1 lx to ensure that vertical illuminance is adequate for making out approaching persons' faces and thus helps afford protection against crime (see pages 3, 11). Other requirements are uniformity of illuminance and adequate glare limitation.

Outdoor car park lighting is an orientation aid and makes persons, vehicles, boundaries and obstructions easier to distinguish. 76

77

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

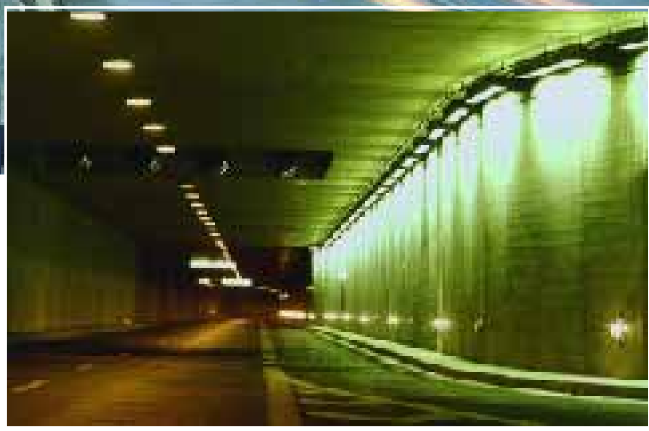
Lighting requirements

Lighting plays a crucial role in making tunnels safe for traffic. The risk of accident during the day is high: the difference in visual conditions between daylight outside and a comparatively dark tunnel entrance requires intense visual concentration. Adaptation from dark to bright conditions at the tunnel exit is not so critical; nor are transitions from outside darkness to a bright tunnel interior at night.

Tunnel lighting needs to be tailored to the adaptive capacity of the human eye. 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 enough. It should be somewhat higher than that of the street lighting outside, however, in order to counteract the oppressive sensation of confinement within the tunnel. In the exit zone, it is advisable to raise the lighting level to

From outside, a tunnel entrance looks like a black hole. A high level of lighting dispels that impression and makes it easier for our eyes to adapt. 78



The lighting inside a tunnel at night should be brighter than the street lighting outside. This counteracts any oppressive sensation of confinement within the tunnel. 80

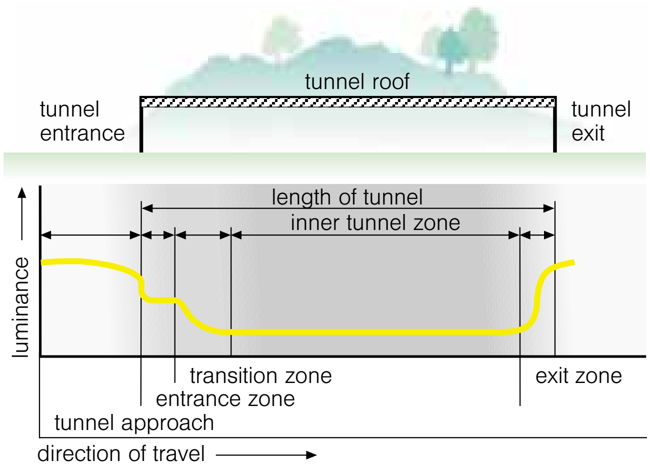


Fig. 81

Luminance in a road tunnel

79

make for a safer transition to daylight brightness.

For underpasses with pedestrian traffic, it is advisable to keep lighting at a high level throughout. The horizontal illuminance should be supplemented by adequate vertical illuminance (semi-cylindrical illuminance, see pages 3 and 11).

Even short underpasses require artificial lighting because they normally have only small coss-sections, which means daylight decreases rapidly within metres. Large underpasses in city centres or underground railway systems are not classed as exterior lighting applications.

Assessment criteria
Requirements for tunnel lighting are set out in DIN 67524, Parts 1 and 2. For tunnels accommodating vehicle traffic, the key lighting quantity is luminance. The level required varies, depending on traffic load and speed limit: 100 to 250 cd/m^2 at 50 km/h, 160 to 320 cd/m^2 at 80 km/h, 250 to 400 cd/m^2 at 100 km/h. The guide values refer to roadway and walls up to a height of 2 m.

Changes in luminance level between tunnel entrance and exit need to be tailored to the adaptive capacity of the eye (see above). Figure 81 shows how the luminance varies.

Adjusting luminance at the tunnel entrance to the fluctuating level of luminance outside is a task performed by special lighting control systems fitted 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, mean horizontal illuminance needs to be 100 lx; at night, 40 lx is enough. Semi-cylindrical illuminance needs to be 25 lx and 10 lx respectively. Care must also be taken to ensure uniformity of lighting and adequate limitation of glare.

Adaptation is less of a problem for pedestrians because they move slower than motorists. Even so, the entrance zone of an underpass should be well lit.

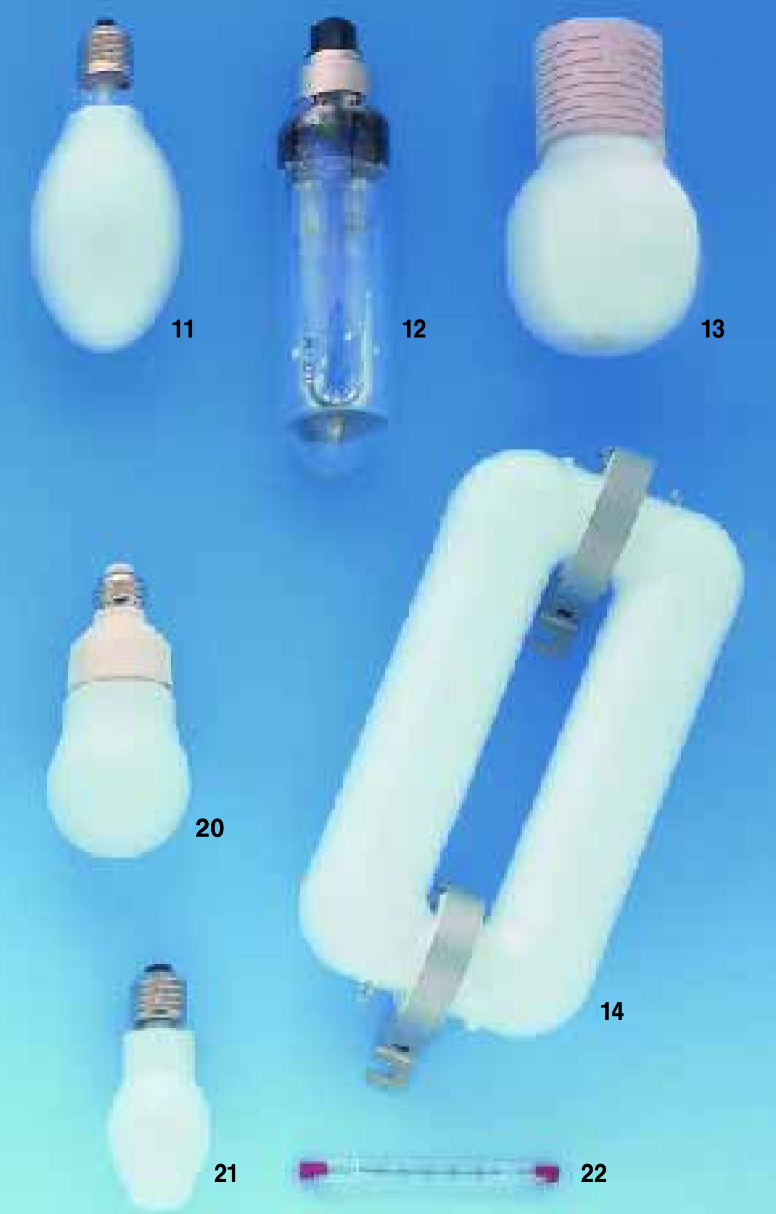
82

83

Safe conduct: the lighting accompanies pedestrians from one end of the underpass to the other. 84

Lamps

Lamp type / Features		tubular	ellipsoid	with xenon	with plug-in base	with double burner	with base at both ends	tubular	ellipsoid	with plug-in base	
		1	2	3	4	5	6	7	8	9	10
		High-pressure sodium vapour lamps						**Metal halide lamps**			
Rating classes (Watt)	**from**	50	35	50	35	50	70	250	70	35	70
	to	1,000	1,000	80	100	400	400	3,500	1,000	150	250
Luminous flux (Lumen)	**from**	4,400	2,200	3,600	1,300	4,000	6,800	20,000	5,200	3,400	6,300
	to	130,000	128,000	6,000	4,700	55,000	48,000	320,000	95,000	12,700	20,000
Luminous efficacy (Lumen/Watt)	**from**	88	63	72	39	80	97	80	74	87	92
	to	130	128	75	48	138	120	91	95	92	95
Light colour		ww	ww	ww	ww	ww	ww	nw, dw	ww, nw, dw	ww	ww
Colour rendering grade		4	4	3	1B	4	4	1A, 2B	1A, 1B, 2B	1B	1B
Base		E27 E40	E27 E40	PG12-3 E27	PG12-1	E27 E40	Fc2 Rx7s	E40	E27 E40	G12	Rx7s Fc2



The principal selection criteria for street 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 11).

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
For incandescent lamps and energy-saving lamps, this is the average service life of the model, defined as the time for which 50 % of lamps operate. For high-pressure sodium vapour lamps, metal halide lamps, induction lamps and tubular fluorescent lamps with plug-in base, economic life ratings are used, taking additional account of the downturn in system luminous flux. System luminous flux must not fall below prescribed minimum levels.

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 electronics industry association ZVEI (see Literature, page 34).

with base at both ends

ellipsoid	tubular	high-output fluorescent lamp	high-output fluorescent lamp	ø 38 mm	three-band lamp ø 26 mm	2-, 4- and – illustrated – 6-tube lamp	2-tube lamp	with E27 screw base	pear-shaped	with jacket	with base at both ends
11	12	13	14	15	16	17	18	19	20	21	22
Mercury vapour	Low-pressure sodium	Induction lamps		Tubular fluorescent lamps		Compact fluorescent lamps		Energy-saving lamps		Tungsten halogen lamps 230 V	
50 1,000	18 180	55 165	100 150	20 65	18 58	5 42	18 55[2]	5 23	5 15	60 250	60 2,000
1,800 58,000	1,800 32,000	3,500 12,000	8,000 12,000	1,150 4,400	1,350 5,200	250 3,200	1,200 4,800	240 1,500	200 900	820 4,200	840 44,000
36 58	100 178	65 73	80	58 68	75[1] 93[1]	50 76	67 88	48 65	40 60	14 17	14 22
ww, nw	–	ww, nw	ww, nw	ww, nw	ww, nw, dw	ww, nw	ww, nw	ww	ww	ww	ww
2B, 3	–	1B	1B	2A, 2B, 3	1B	1B	1B	1B	1B	1A	1A
E27 E40	BY22d	Spezial	Spezial	G13	G13	G23 G24, 2G7 GX24	2G11	E27	E27	E27	R7s

1) Where lamps are operated by electronic ballasts, luminous efficacy is increased to 81–100 lm/W. Power consumption decreases from 18 W to 16 W, from 36 W to 32 W and from 58 W to 50 W.

2) 40 W and 5 W only with EB

ww = warm white
colour temperature below 3,300 K

nw = neutral white
colour temperature 3,300 to 5,000 K

dw = daylight white
temperature over 5,000 K

Luminaires should be selected on the basis of the lighting requirements set out in DIN 5044 and the stipulations of any special regulations relating to the application in question. Secondly – but not of secondary importance – is the matter of luminaire design, the visual impact the luminaires make during the day.

It definitely pays to invest in quality luminaires. Crucial advantages of their design and manufacture are
• high light output ratios for economical operation
• lighting quality and functionality
• mechanical and electrical reliability (VDE, ENEC)
• long service life (material quality, surface treatment, compact design)
• quality control throughout production
• easy assembly and low maintenance
In addition, manufacturers of quality luminaires offer professional advice and assistance with planning.

Special attention should be paid to the degree of protection: the higher it is, the greater the luminaire's resistance to external factors and the longer its useful life. It is recommended that the luminaire wiring compartment should be protected to at least IP 23 and the lamp compartment to at least IP 54. The table on the right lists and explains all the IP codes (Ingress Protection). The first numeral (1–6) describes the degree of protection against solid foreign bodies, the second (1–8) indicates protection against moisture. The higher degrees of protection also indicate conformity to the degrees lower down the scale.

Fig. 85

Street luminaire with high-pressure sodium vapour lamps or metal halide lamps for thoroughfare lighting.

Fig. 86

Street luminaire with high-pressure sodium vapour lamps, metal halide lamps or compact fluorescent lamps for collector streets, local service streets, residential streets and outdoor car parks.

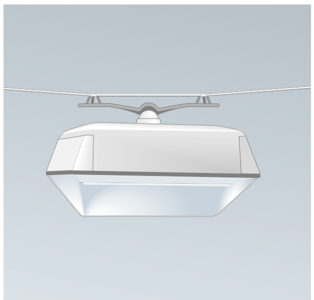


Fig. 87

Pendant luminaire with high-pressure sodium vapour lamps, metal halide lamps or high-pressure mercury vapour lamps for suspension on catenary (overhead) wires for thoroughfares.

Fig. 91

Secondary luminaire with high-pressure sodium vapour lamps or metal halide lamps and indirect optical control system for decorative lighting in pedestrian precincts and downtown squares.

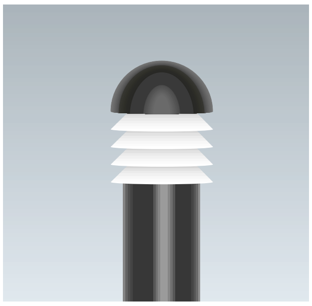


Fig. 92

Bollard luminaire with compact fluorescent lamps, energy-saving lamps, tungsten halogen lamps or incandescent lamps for path lighting in parks and gardens.

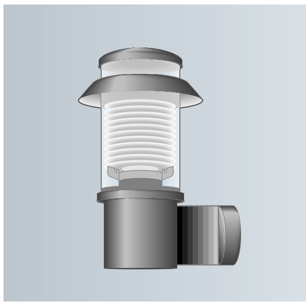


Fig. 93

Wall luminaire with tungsten halogen lamps, incandescent lamps, energy-saving lamps or compact fluorescent lamps for mounting on buildings, e.g. in parks and gardens or narrow downtown streets.

Numeral	**1st numeral**	Protection against foreign bodies and physical contact	**2nd numeral**	Protection against water
0	unprotected		unprotected	
1	protected against solid foreign bodies >15 mm		protected against drops of water falling vertically	
2	protected against solid foreign bodies >12 mm		protected against drops of water falling up to 15° from the vertical	
3	protected against solid foreign bodies >2,5 mm		protected against spraywater	
4	protected against solid foreign bodies >1 mm		protected against splashwater	
5	protected against harmful dust deposits		protected against jetwater	
6	protected against ingress of dust		protected against floodwater	
7	–		protected against the effects of immersion	
8	–		protected against effects of submersion	…m

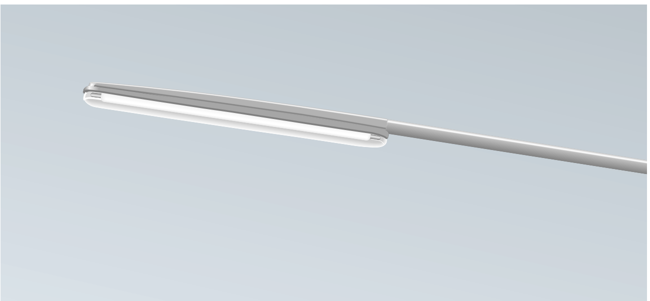


Fig. 88

Street luminaire with tubular fluorescent lamps for local service street lighting.

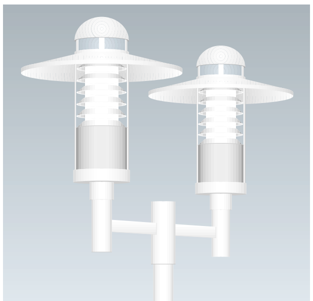


Fig. 89

Decorative luminaire with high-pressure sodium vapour lamps, metal halide lamps, high-pressure mercury vapour lamps or compact fluorescent lamps for service streets, residential streets, squares and pedestrian precincts.

Fig. 90

Decorative luminaire with high-pressure sodium vapour lamps, metal halide lamps, high-pressure mercury vapour lamps or compact fluorescent lamps for pedestrian precincts and squares; also suitable for service streets, residential streets and path lighting.

Fig. 94

Pedestal luminaire with incandescent lamps, tungsten halogen lamps, energy-saving lamps or compact fluorescent lamps for mounting on walls or pillars in parks and gardens as well as for paths leading to buildings.

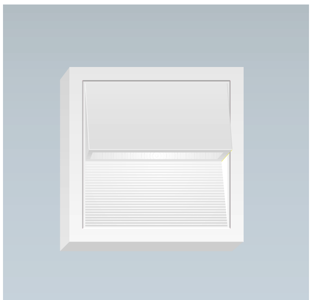


Fig. 95

Recessed wall luminaire with compact fluorescent lamps, energy-saving lamps or tungsten halogen lamps for path lighting, mainly used on stairs and approach paths.

Fig. 96

Flood with high-pressure sodium vapour lamps, metal halide lamps or tungsten halogen lamps for illuminating buildings, artworks or vegetation.

Fig. 97

Recessed ground flood with high-pressure sodium vapour lamps, metal halide lamps or tungsten halogen lamps for floodlighting from below.

Fig. 98

Luminaire with high-pressure sodium vapour lamps or metal halide lamps for pedestrian crossing lighting.

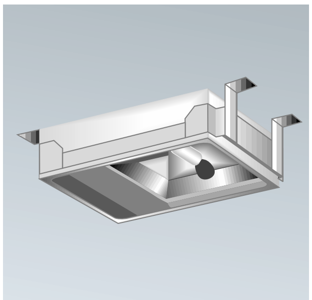


Fig. 99

Luminaire with high-pressure sodium vapour lamps or metal halide lamps for tunnel lighting.

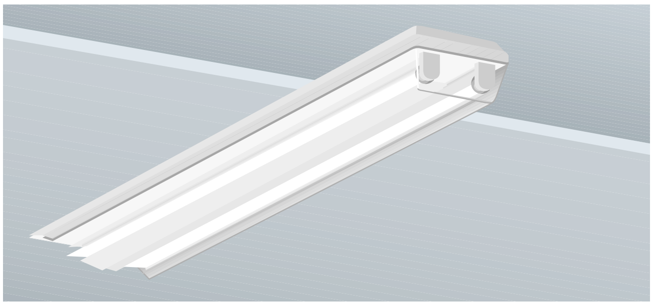


Fig. 100

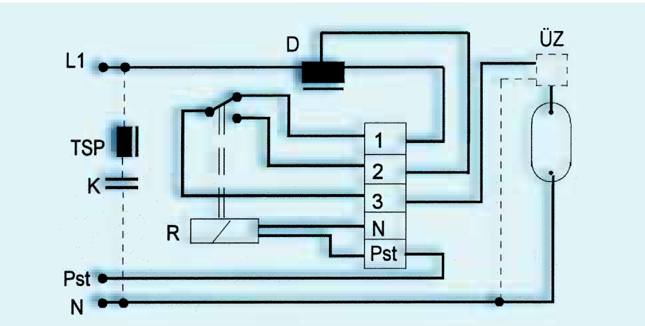
Damp-proof luminaire with tubular fluorescent lamps for indoor car park and underpass lighting.

Lowered night-time lighting

During the night, when traffic is light – e.g. between the hours of 11 p.m. and 5 a.m. – the level of street lighting can be lowered. This is a widely accepted way of saving energy. Around half of all the exterior luminaires used in public lighting systems in Germany are powered down at night.

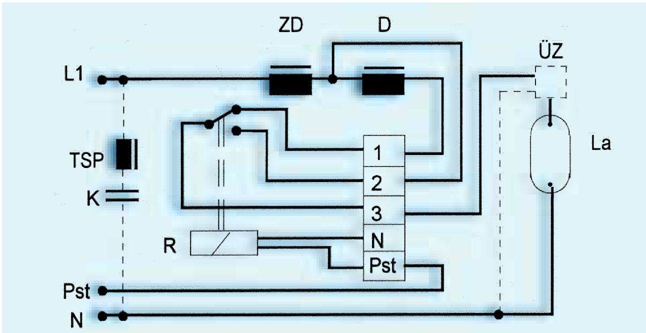
For single-lamp luminaires, lowering the lighting level at night means reducing the lamp power of each individual light source, e.g. from 80 W to 50 W (power reduction). This preserves the uniformity of the lighting, which would not be the case in a single-lamp luminaire system where every second luminaire 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.

Where luminaires are single-lamped, the only acceptable way to power down to a lower night-time lighting level is to reduce the connected load of each light source. 101



L1	phase	K	p.f. capacitor
N	neutral	TSP	AF reactor
Pst	control phase	La	lamp
D	choke	Üz	superimposed-pulse ignitor
		R	relay

Power reduction with tapped choke. Fig. 102



L1	phase	K	p.f. capacitor
N	neutral	TSP	AF reactor
Pst	control phase	La	lamp
D	choke	Üz	superimposed-pulse ignitor
ZD	additional choke	R	relay

Power reduction with additional choke. Fig. 103

Switching off lamps to lower the lighting level at night is possible only where two or more luminaires are mounted on the same mast (one luminaire always stays on) or 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 or luminaires are switched off alternately so that the life expectancy of each lamp decreases at the same rate.

Lighting components
With high-pressure discharge lamps, power reduction calls for a ballast with integrated power reduction circuitry. Power reduction is achieved by tapping the choke or by using an additional choke; changeover switching is by relay.

Electronic ballasts (EBs) are now widely used in street 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 lighting components are already very good: igniters which automatically cut out at the end of a lamp's service life work without an EB; even modern computerised master/slave control systems require no EB.

Precisely when the national standard DIN 5044 "Stationary street lighting" will be replaced by the European standard DIN EN 13201 "Street lighting" is not yet known. 104

The information contained in this booklet is based on the DIN standards and VDE stipulations in force at the time of going to press (December 1999). In the foreseeable future, national industrial standards in member states of the European Union (in Germany: DIN) will be replaced by European standards (EN).

DIN 5044 "Stationary traffic lighting" will be replaced by DIN EN 13201 "Street lighting"
Part 1: Quality criteria with appendix for lighting class selection
Part 2: Calculation of quality criteria
Part 3: Methods for measuring quality criteria

DIN 67523 "Lighting of pedestrian crossings (Road sign 293 Road Traffic Act) and supplementary lighting" will be replaced by corresponding sections of DIN EN 13201.

DIN 67528 "Lighting of parking areas and indoor car parks" will be superseded as regards indoor car park (garage) lighting. In its place will be standards for indoor car parks contained in DIN EN 12464 "Workplace lighting".

The specifications set out for outdoor car parks will be replaced by corresponding sections of DIN EN 13201 (especially lighting classes S and A)

DIN 67524 "Lighting of street-tunnels and underpasses" will not be replaced for the moment. As regards tunnel lighting, plans at EU level are only for a "Technical Report".

Contents of the forthcoming standard DIN EN 13201
The street for which lighting is required needs to be assigned to a situation class and thence to the lighting class corresponding to it.

The situation classes A to E are defined by
• the speed limit which needs to be observed by the principal road user (high > 60 km/h, medium 30 to 60 km/h, low 5 to 30 km/h, very low < 5 km/h).
• the nature of the principal road user and other road users (motor traffic, slow vehicles, bicycles, pedestrians).

In every situation class, the following parameters need to be assessed for assignment to the lighting classes ME, CE, S, A, ES or EV (see table):
• weather conditions (dry, wet)
• stuctural conditions
• traffic intensity (average, in motor vehicles/hour)
• permission to park

Lighting classes	Applications	Lighting quality criteria
ME 1 to ME 6	medium and high motor vehicle speeds; for wet roads: classes MEW 1 bis MEW 5	Luminance: L_m and U_{0i} and U_i and TI; Surrounding Ratio (SR) = 0,5
CE 0 to CE 5	as for ME classes but with "conflict areas", i.e. shopping streets, crossroads, T-junctions, roundabouts, traffic congestion zones, streets with pedestrians and cyclists; applies also to underpasses and staircases	Illuminance: E_m and $U_{0i} = E_{min}/\bar{E} = 0{,}4$
S 1 to S 7	pedestrian and cyclist zones, hard shoulder and other zones not on the roadway, prestige streets, footpaths, park roads, school yards	Illuminance: $\bar{E}_m$ and E_{min}
A 1 to A 6	as for S classes	Hemispherical illuminance: E_{hs} and $U_0 = E_{hs,\,min}/\bar{E}_{hs}$
ES 1 to ES 9	areas where lighting is intended to help reduce crime and combat subjective feelings of insecurity	Additional appraisal by semi-cylindrical illuminance $E_{sc,\,min}$
EV 1 to EV 6	Turnpikes, transshipment points, shunting areas, etc.	Additional appraisal by vertical illuminance $E_{v,\,min}$

• crime risk
• need to be able to make out approaching persons'-faces
•"conflict area" status of the street (intersecting traffic streams)
• complexity of the visual field and degree of orientational difficulty
• ambient brightness

Appended to each lighting class is a numerical suffix: the higher the numeral the lower the requirements.

105

Street lighting installed before the European standard DIN EN 13201 becomes effective is covered by current national standards.

The European street lighting standard contains a table summarising the quality criteria required for the individual lighting classes.

What else will change
Other major differences between EN 13201 and DIN 5044:

• In many instances, the European standard recommends that lighting should encompass areas which border on the roadway, illuminating these "surrounding areas" to a depth of half the roadway's width with half of the roadway illuminance.
• EN 13201 makes no provision for planning factors. Instead, it sets out servicing thresholds, which illuminance and luminance must never fall below.
• In streets where luminance is the key criterion, glare is assessed by the TI method (see page 11).
• Glare can also be assessed on the basis of standard luminous intensity ceilings and by the glare index (GI) method.

Present position
At the end of 1999, the European standards for exterior lighting exist only in draft form. They are not due to be adopted before the end of the year 2000. When they come into force, they will apply to new lighting systems only; systems installed prior to the introduction of the relevant European standard will be covered by current national standards.

Literature

DIN 5044 Stationary traffic lighting – Street lighting for automobile traffic
Part 1: General requirements and recommendations
Part 2: Calculation and measurement

DIN EN 13201 Street lighting – draft –
Part 1: Quality criteria with appendix for lighting class selection
Part 2: Calculation of quality criteria
Part 3: Methods for measuring quality criteria

DIN 67523 Lighting of pedestrian crossings (Road sign 293 Road Traffic Act) and supplementary lighting

DIN 67528 Lighting of parking areas and indoor car parks

DIN EN 12464 Workplace lighting – draft – "Garages" section

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

Uschkamp, G.: **Straßenbeleuchtung und Verkehrssicherheit.** Berichte der Bundesanstalt für Straßenwesen (BaSt), (Street lighting and road safety. Reports of the Federal Highways Institute) Bergisch Gladbach, in "Verkehrstechnik" vol. 14, Bergisch Gladbach, February 1994

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Fachverband Elektrische Lampen within the Zentralverband der Elektronik- und Elektroindustrie (ZVEI) e.V.: **Lebensdauerverhalten von Entladungslampen für Beleuchtung** (Service life of discharge lamps for lighting), Frankfurt am Main

ZVEI, Stresemannallee 19, 60596 Frankfurt am Main

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Fördergemeinschaft
Gutes Licht
Postfach 70 12 61
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Deutschland

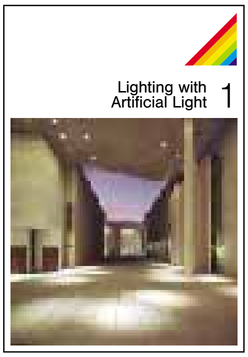
Information from Fördergemeinschaft Gutes Licht

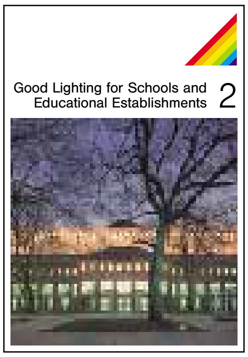
Fördergemeinschaft Gutes Licht (FGL) provides information on the advantages of good lighting and offers extensive material dealing with every aspect of artificial lighting and its correct usage. FGL information is impartial and based on current DIN standards and VDE stipulations.

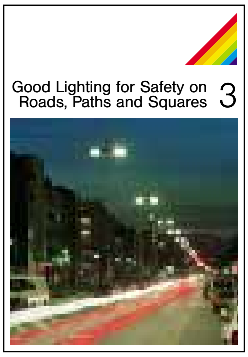
Information on Lighting Applications
The booklets 1 to 15 in this series of publications are designed to help anyone who becomes involved with lighting – planners, decision-makers, investors – to acquire a basic knowledge of the subject. This facilitates cooperation with lighting and electrical specialists. The lighting information contained in all these booklets is of a general nature.

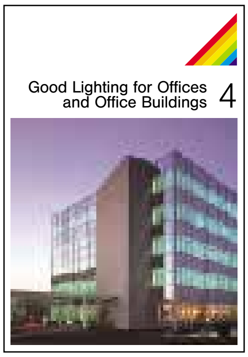
Lichtforum
Lichtforum is a specialist periodical devoted to topical lighting issues and trends. It is published at irregular intervals.

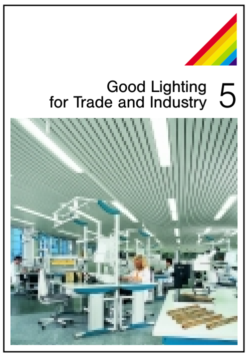
www.licht.de
FGL is also on the Internet. Its website “www.german-lighting.org” offers tips on correct lighting for a variety of domestic and commer-cial “Lighting Situations”. These are linked to a “Product/Manufacturer” matrix which not only lists products but also contains the addresses of the more than 140 FGL members. Under “FGL publications”, visitors can view specimen pages of all FGL print publications. Other site features include hotlinks and a discussion forum.

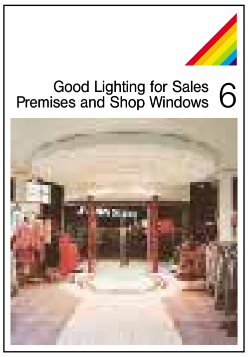


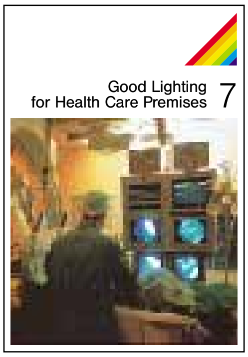


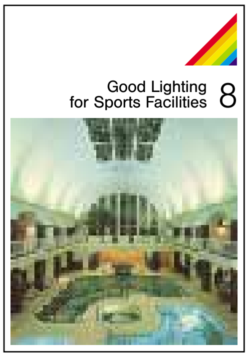


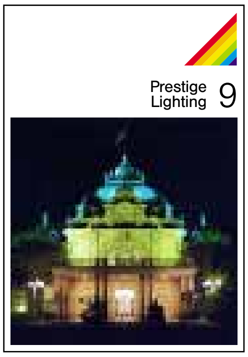


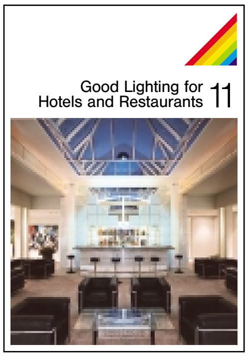


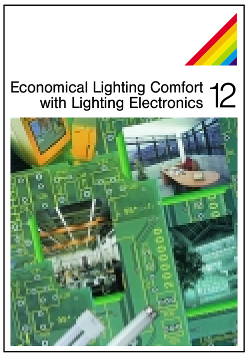












Information on
Lighting Applications
Booklet **3**

Good Lighting for Safety on Roads, Paths and Squares

Fördergemeinschaft Gutes Licht