Lighting with Artificial Light
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>From nature's light ... to artificial lighting</td>
<td>2 / 3</td>
</tr>
<tr>
<td>The physics of light</td>
<td>4 / 5</td>
</tr>
<tr>
<td>The physiology of light</td>
<td>6 / 7</td>
</tr>
<tr>
<td>The language of lighting technology</td>
<td>8 / 9</td>
</tr>
<tr>
<td>Quality features in lighting</td>
<td>10</td>
</tr>
<tr>
<td>Lighting level - maintained illuminance and luminance</td>
<td>11</td>
</tr>
<tr>
<td>Glare limitation - direct glare</td>
<td>12</td>
</tr>
<tr>
<td>Glare limitation - reflected glare</td>
<td>13</td>
</tr>
<tr>
<td>Harmonious distribution of brightness</td>
<td>14</td>
</tr>
<tr>
<td>Direction of light and modelling</td>
<td>15</td>
</tr>
<tr>
<td>Light colour</td>
<td>16</td>
</tr>
<tr>
<td>Colour rendering</td>
<td>17</td>
</tr>
<tr>
<td>Light generation by thermal radiators and discharge lamps</td>
<td>18 / 19</td>
</tr>
<tr>
<td>Overview of lamps</td>
<td>20 / 21</td>
</tr>
<tr>
<td>Luminaires - General requirements and lighting characteristics</td>
<td>22 / 23</td>
</tr>
<tr>
<td>Luminaires - Electrical characteristics, ballasts</td>
<td>24 / 25</td>
</tr>
<tr>
<td>Luminaires - Operating devices, regulation, control, BUS systems</td>
<td>26 / 27</td>
</tr>
<tr>
<td>Review of luminaires</td>
<td>28 / 29</td>
</tr>
<tr>
<td>Lighting planning</td>
<td>30 / 31</td>
</tr>
<tr>
<td>Lighting costs</td>
<td>32</td>
</tr>
<tr>
<td>Measuring lighting systems</td>
<td>33</td>
</tr>
<tr>
<td>Lighting and the environment</td>
<td>34</td>
</tr>
<tr>
<td>Literature, acknowledgements for photographs. order cards</td>
<td>35</td>
</tr>
<tr>
<td>Imprint</td>
<td>36</td>
</tr>
<tr>
<td>Information from Fördergemeinschaft Gutes Licht</td>
<td>37</td>
</tr>
</tbody>
</table>
Booklet 1 of the Information on Lighting Applications series published by Fördergemeinschaft Gutes Licht is intended for all those who want to delve into the topic of light and lighting or wish to familiarize themselves with the basics of lighting technology. The present edition (published July 2004) is a revised version of the May 2000 edition taking account of all current standards.

It also forms the introduction to a series of publications designed to provide useful information on lighting applications for all those involved in planning or decision-making in the field of lighting.

One of the objectives of the series is to promote awareness of a medium which we generally take for granted and use without a second thought.

It is only when we get involved in “making” light, in creating artificial lighting systems, that things get more difficult, more technical.

Effective lighting solutions naturally call for expertise on the part of the lighting designer. But a certain amount of basic knowledge is also required by the client, if only to facilitate discussion on “good lighting” with the experts.

This publication and the other booklets in the series are designed to convey the key knowledge and information about light, lamps and luminaires needed to meet those requirements.

Light is not viewed in these booklets as simply a physical phenomenon; it is considered in all its implications for human life. As the radiation that makes visual contact possible, light plays a primarily physiological role in our lives by influencing our visual performance; it also has a psychological impact, however, helping to define our sense of wellbeing.

Furthermore, light has a chronobiological effect on the human organism. We know today that the retina of the eye has a special receptor which regulates such things as the sleep hormone melatonin. Light thus helps set and synchronize our “biological clock”, the circadian rhythm that regulates active and passive phases of biological activity according to the time of day and year.

So the booklets published by Fördergemeinschaft Gutes Licht not only set out to provide information about the physics of light; they also look at the physiological and psychological impact of “good lighting” and provide ideas and advice on the correct way to harness light for different applications – from street lighting to lighting for industry, schools and offices, to lighting for the home.

Illustrations:
01 “Café Terrace at Night” (1888), Vincent Van Gogh (1853 – 1890), Rijksmuseum Kröller-Müller, Otterlo, Netherlands
02 “The Artist’s Sister with a Candle” (1847), Adolf Menzel (1815 – 1905), Neue Pinakothek, Munich, Germany
03 “The Sleepwalker” (1927), René Magritte (1898 – 1967), privately owned
04 Installation, Maurizio Nanucci (1992)
Light is life. The relationship between light and life cannot be stated more simply than that. Most of the information we receive about our surroundings is provided by our eyes. We live in a visual world. The eye is the most important sense organ in the human body, handling around 80% of all incoming information. Without light, that would be impossible – light is the medium that makes visual perception possible.

The light of the sun, venerated in ancient cultures as a god, determines the pulse of life and the constant yet subtly changing alternation of day and night.

Insufficient light or darkness gives rise to a sense of insecurity. We lose vital bearings. Artificial lighting during the hours of darkness makes us feel safe.

So light not only enables us to see; it also affects our mood and sense of wellbeing.

The light of the moon and stars has only 1/500,000th of the intensity of sunlight. But the sensitivity of our eyes still enables us to see.

Lighting level and light colour, modelling and switches from light to dark impact on momentary sensations and determine the rhythm of our lives.

In sunlight, for instance, illuminance is about 100,000 lux. In the shade of a tree it is around 10,000 lux, while on a moonlit night it is 0.2 lux, and even less by starlight.

People nowadays spend most of the day indoors – in illuminances between 50 and 500 lux. Light sets the rhythm of our biological clock but it needs to be relatively intense to have an effect on the circadian system (> 1000 lux), so for most of the time we live in “chronobiological darkness”. The consequences are troubled sleep, lack of energy, irritability, even severe depression.

As we said above, light is life. Good lighting is important for seeing the world around us. What we want to see needs to be illuminated. Good lighting also affects the way we feel, however, and thus helps shape our quality of life.
Around 300,000 years ago, man began to use fire as a source of warmth and light. The glowing flame enabled people to live in caves where the rays of the sun never penetrated.

The magnificent drawings in the Altamira cave – artworks dating back some 15,000 years – can only have been executed in artificial light. The light of campfires, of kindling torches and oil and tallow lamps radically changed the way prehistoric man lived.

But light was not only used in enclosed spaces. It was also harnessed for applications outdoors. Around 260 BC, the Pharos of Alexandria was built, and evidence from 378 AD suggests there were “lights in the streets” of the ancient city of Antioch.

Ornamental and functional holders for the precious light-giving flame appear at a very early stage in the historical record. But the liquid-fuel lamps used for thousands of years underwent no really major improvement until Aimé Argand’s invention of the central burner in 1783.

That same year, a process developed by Dutchman Jan Pieter Minckelaers enabled gas to be extracted from coal for streetlamps. Almost simultaneously, experiments started on electric arc lamps – fuelling research which acquired practical significance in 1866 when Werner Siemens succeeded in generating electricity economically with the help of the dynamo. But the real dawn of the age of electric light came in 1879, with Thomas A. Edison’s “re-invention” and technological application of the incandescent lamp invented 25 years earlier by the German clock-maker Johann Heinrich Goebel.

With each new light source – from campfire and kindling to candle and electric light bulb – “luminaires” were developed to house and harness the new “lamps”. In recent decades, lamp and luminaire development has been particularly dynamic, drawing on the latest technologies, new optical systems and new materials while at the same time maximising economic efficiency and minimising environmental impact.

For the majority of people today, life without artificial lighting would be unimaginable.

For more than 2,000 years, artificial lighting has illuminated the night and provided security and bearings for human beings.
The physics of light

Man has always been fascinated by light and has constantly striven to unravel its mysteries. History has produced various theories that today strike us as comical but were seriously propounded in their time. For example, since no connection could be discerned between a flame and the object it rendered visible, it was at one time supposed that “visual rays” were projected by the eyes and reflected back by the object. Of course, if this theory were true, we would be able to see in the dark...

In 1675, by observing the innermost of the four large moons of Jupiter discovered by Galileo, O. Römer was able to estimate the speed of light at $2.3 \times 10^8$ m/s.

A more precise measurement was obtained using an experimental array devised by Léon Foucault: $2.98 \times 10^8$ m/s. The speed of light in empty space and in air is generally rounded up to $3 \times 10^8$ m/s or 300,000 km/s.

This means that light takes around 1.3 seconds to travel from the Moon to the Earth and about $8\frac{1}{3}$ minutes to reach the Earth from the Sun. Light takes 4.3 years to reach our planet from the fixed star Alpha in Centaurus, about 2,500,000 years from the Andromeda nebula and more than 5 billion years from the most distant spiral nebulae.

Different theories of light enable us to describe observed regularities and effects.

The corpuscular or particle theory of light, according to which units of energy (quanta) are propagated at the speed of light in a straight line from the light source, was proposed by Isaac Newton. The wave theory of light, which suggests that light moves in a similar way to sound, was put forward by Christiaan Huygens. For more than a hundred years, scientists could not agree which theory was correct. Today, both concepts are used to explain the properties of light: light is the visible part of electromagnetic radiation, which is made up of oscillating quanta of energy.

It was Newton again who discovered that white light contains colours. When a narrow beam of light is directed onto a glass prism and the emerging rays are projected onto a white surface, the coloured spectrum of light becomes visible.

In a further experiment, Newton directed the coloured rays onto a second prism, from which white light once again appeared. This was the proof that white sunlight is the sum of all the colours of the spectrum.

In 1822, Augustin Fresnel succeeded in determining the wavelength of light and showing that each spectral colour has a specific wavelength. His statement that “light brought to light creates darkness” sums up his realization that light rays of the same wavelength cancel each other out when brought together in corresponding phase positions.

Max Planck expressed the quantum theory in the formula:

\[ E = h \cdot \nu \]

The energy $E$ of an energy quantum (of radiation) is proportional to its frequency $\nu$, multiplied by a constant $h$ (Planck’s quantum of action).
The Earth’s atmosphere allows visible, ultraviolet and infrared radiation to pass through in such a way that organic life is possible. Wavelengths are measured in nanometres (nm) = $10^{-9}$ m = $10^{-7}$ cm. One nanometre is a ten-millionth of a centimetre.

Light is the relatively narrow band of electromagnetic radiation to which the eye is sensitive. The light spectrum extends from 380 nm (violet) to 780 nm (red).

Each wavelength has a distinct colour appearance, and from short-wave violet through blue, green, green-yellow, orange up to long-wave red, the spectrum of sunlight exhibits a continuous sequence. Coloured objects only appear coloured if their colours are present in the spectrum of the light source. This is the case, for example, with the sun, incandescent lamps and fluorescent lamps with very good colour rendering properties.

Above and below the visible band of the radiation spectrum lie the infrared (IR) and ultraviolet (UV) ranges. The IR range encompasses wavelengths from 780 nm to 1 nm and is not visible to the eye. Only where it encounters an object is the radiation absorbed and transformed into heat. Without this heat radiation from the sun, the Earth would be a frozen planet. Today, thanks to solar technology, IR radiation has become important both technologically and ecologically as an alternative energy source.

For life on Earth, the right amount of radiation in the UV range is important. This radiation is classed according to its biological impact as follows:

- UV-A (315 to 380 nm), suntan, solaria;
- UV-B (280 to 315 nm), erythema (reddening of the skin), sunburn;
- UV-C (100 to 280 nm), cell destruction, bactericidal lamps.

Despite the positive effects of ultraviolet radiation – e.g. UV-B for vitamin D synthesis – too much can cause damage. The ozone layer of the atmosphere protects us from harmful UV radiation, particularly from UV-C. If this layer becomes depleted (ozone gap), it can have negative consequences for life on Earth.

The prism combines the spectral colours to form white light. Sunlight is the combination of all the colours of its spectrum.

When the artificial light from a fluorescent lamp is split up, the individual spectral colours are seen to be rendered to a greater or lesser extent, depending on the type of lamp.

Compared with its appearance in daylight, a red rose looks unnatural under the monochromatic yellow light of a low-pressure sodium vapour lamp. This is because the spectrum of such light contains no red, blue or green, so those colours are not rendered.
The eye is a sensory organ with extraordinary capabilities. Just a few highly sensitive “components” complement each other to form a remarkable visual instrument:

- The optical components of the eye can be compared to a photographic camera.

The image-producing optics consist of the cornea, the lens and the intervening aqueous humour. Alteration of the focal length needed for accurate focusing on objects at varying distances is effected by an adjustment of the curvature of the refractive surfaces of the lens. With age, this accommodative capacity decreases, due to a hardening of the lens tissue.

With its variable central opening – the pupil – the iris in front of the lens functions as an adjustable diaphragm and can regulate the incident luminous flux within a range of 1:16. At the same time, it improves the depth of field. The inner eye is filled with a clear, transparent mass, the vitreous humour.

The retina on the inner wall of the eye is the “projection screen”. It is lined with some 130 million visual cells. Close to the optical axis of the eye there is a small depression, the fovea, in which the visual cells for day and colour vision are concentrated. This is the region of maximum visual acuity.

Depending on the level of brightness (luminance), two types of visual cell – cones and rods – are involved in the visual process.

The 120 million rods are highly sensitive to brightness but relatively insensitive to colour. They are therefore most active at low luminance levels (night vision); their maximum spectral sensitivity lies in the blue-green region at 507 nm.

The 7 million or so cones are the more sensitive receptors for colour. These take over at higher levels of luminance to provide day vision. Their maximum spectral sensitivity lies in the yellow-green range at 555 nm. There are three types of cone, each with a different spectral sensitivity (red, green, blue), which combine to create an impression of colour. This is the basis of colour vision.

The ability of the eye to adjust to higher or lower levels of luminance is termed adaptation.

The adaptive capacity of the eye extends over a luminance ratio of 1:10 billion. The pupils control the luminous flux entering the eyes within a range of only 1:16, while the “parallel switching” of the ganglion cells enables the eye to adjust to the far wider range. The state of adaptation affects visual performance at any moment, so that the higher the level of lighting, the more visual performance will be improved and visual errors minimized. The adaptive process and hence adaptation time depend on the luminance at the beginning and end of any change in brightness.

Dark adaptation takes longer than light adaptation. The eye needs about 30 minutes to adjust to darkness outdoors at night after the higher lighting level of a workroom. Only a few seconds are required, however, for adaptation to brighter conditions.

Sensitivity to shapes and visual acuity are prerequisites for identification of details. Visual acuity depends not only on the state of adaptation but also on the resolving power of the retina and the quality of the optical image.

Two points can just be perceived as separate when...
their images on the retina are such that the image of each point lies on its own cone with another “unstimulated” cone between them. Inadequate visual acuity can be due to eye defects, such as short- or long-sightedness, insufficient contrast, insufficient illuminance.

4. **Four minimum requirements need to be met to permit perception and identification:**

1. **A minimum luminance** is necessary to enable objects to be seen (adaptation luminance). Objects that can be identified in detail easily during the day become indistinct at twilight and are no longer perceptible in darkness.

2. For an object to be identified, there needs to be a difference between its brightness and the brightness of the immediate surroundings (minimum contrast). Usually this is simultaneously a colour contrast and a luminance contrast.

3. Objects need to be of a minimum size.

4. Perception requires a minimum time. A bullet, for instance, moves much too fast. Wheels turning slowly can be made out in detail but become blurred when spinning at higher velocities. The challenge for lighting technology is to create good visual conditions by drawing on our knowledge of the physiological and optical properties of the eye – e.g. by achieving high luminance and an even distribution of luminance within the visual field.
The language of lighting technology

Luminous flux $\Phi$ is the rate at which light is emitted by a lamp. It is measured in lumens (lm). Ratings are found in lamp manufacturers' lists.

The luminous flux of a 100 W incandescent lamp is around 1380 lm, that of a 20 W compact fluorescent lamp with built-in electronic ballast around 1200 lm.

Luminous intensity $I$ is the amount of luminous flux radiating in a particular direction. It is measured in candelas (cd).

The way the luminous intensity of reflector lamps and luminaires is distributed is indicated by curves on a graph. These are known as intensity distribution curves (IDCs).

To permit comparison between different luminaires, IDCs usually show 1000 lm (= 1 klm) curves. This is indicated in the IDC by the reference cd/klm. The form of presentation is normally a polar diagram, although xy graphs are often found for floodlights.

Luminous efficacy $\eta$ is the luminous flux of a lamp in relation to its power consumption. Luminous efficacy is expressed in lumens per watt (lm/W).

For example, an incandescent lamp produces approx. 14 lm/W, a 20 W compact fluorescent lamp with built-in EB approx. 60 lm/W.

Light output ratio $\eta_{LB}$ is the ratio of the radiant luminous flux of a luminaire to the luminous flux of the fitted lamp. It is measured in controlled operating conditions.

Glare is annoying. It can be caused directly by luminaires or indirectly by reflective surfaces. Glare depends on the luminance and size of the light source, its position in relation to the observer and the brightness of the surroundings and background. Glare should be minimized by taking care over luminaire arrangement and shielding, and taking account of reflectance when choosing colours and surface structures for walls, ceiling and floor. Glare cannot be avoided altogether. It is especially important to avoid direct glare in street lighting as this affects road safety.

Where VDU workplaces are present, special precautions must be taken to avoid reflected glare.

Reflectance $\rho$ indicates the percentage of luminous flux reflected by a surface. It is an important factor for calculating interior lighting.

Dark surfaces call for high illuminance, lighter surfaces require a lower illuminance level to create the same impression of brightness.

In street lighting, the three-dimensional distribution of the reflected light caused by directional reflectance (e.g. of a worn road surface) is an important planning factor.
Luminance $L$ indicates the brightness of an illuminated or luminous surface as perceived by the human eye. It is measured in units of luminous intensity per unit area (cd/m²). For lamps, the “handier” unit of measurement cd/cm² is used.

Luminance describes the physiological effect of light on the eye; in exterior lighting it is an important value for planning.

With fully diffuse reflecting surfaces – of the kind often found in interiors – luminance in cd/m² can be calculated from the illuminance $E$ in lux and the reflectance $\rho$:

$$L = \frac{\rho \cdot E}{\pi}$$

Illuminance $E$ is measured in lux (lx) on horizontal and vertical planes. Illuminance indicates the amount of luminous flux from a light source falling on a given surface.

Maintained illuminance $E_m$ and luminance $L_m$ depend on the visual task to be performed. Illuminance values for interior lighting are set out in the harmonized European standard DIN EN 12464-1. Illuminance and luminance values for street lighting are stipulated in DIN EN 13201-2. Sports facility lighting is covered by another harmonized European standard, DIN EN 12193. Maintained values are the values below which average values on a specified surface are not allowed to fall.

Uniformity of illuminance or luminance is another quality feature. It is expressed as the ratio of minimum to mean illuminance ($g_1 = \frac{E_{\text{min}}}{E}$) or, in street lighting, as the ratio of minimum to mean luminance ($U_0 = \frac{L_{\text{min}}}{L}$).

In certain applications, the ratio of minimum to maximum illuminance $g_2 = \frac{E_{\text{min}}}{E_{\text{max}}}$ is important.

Maintenance factor
With increasing length of service, illuminance decreases as a result of ageing and soiling of lamps, luminaires and room surfaces.

Under the harmonized European standards, designer and operator need to agree and record maintenance factors defining the illuminance and luminance required on installation to ensure the values which need to be maintained.

Where this is not possible, a maintenance factor of 0.67 is recommended for interiors subject to normal ageing and soiling; this may drop as low as 0.5 for rooms subject to special soiling.

For “sports facility lighting”, DIN EN 12193 stipulates a maintenance factor of 0.8. Maintained value and maintenance factor define the value required on installation: maintained value = value on installation x maintenance factor.
Quality features in lighting

Just as the nature of occupational and recreational activities differs – e.g. reading a book, assembling miniature electronic components, executing technical drawings, running colour checks in a printing works, etc. – so too do the requirements presented by visual tasks. And those requirements define the quality criteria a lighting system needs to meet.

Careful planning and execution are prerequisites for good quality artificial lighting. This is what specific “quality features” determine:

- **lighting level** – brightness,
- **glare limitation** – vision undisturbed by either direct or indirect glare,
- **harmonious distribution of brightness** – an even balance of luminance,
- **light colour** – the colour appearance of lamps, and in combination with
- **colour rendering** – correct recognition and differentiation of colours and room ambience,
- **direction of light and modelling** – identification of three-dimensional form and surface textures.

Depending on the use and appearance of a room, these “quality features” can be given different weightings. The emphasis may be on:

- **visual performance**, which is affected by lighting level and glare limitation,
- **visual comfort**, which is affected by colour rendering and harmonious brightness distribution,
- **visual ambience**, which is affected by light colour, direction of light and modelling.
Lighting level –
Maintained illuminance and luminance

Lighting level is influenced by illuminance and the reflective properties of the surfaces illuminated. It is a defining factor of visual performance.

Some examples of reflectance:
- white walls up to 85%
- light-coloured wood paneling up to 50%
- red bricks up to 25%

The lower the reflectance and the more difficult the visual task, the higher the illuminance needs to be.

Maintained illuminance
Maintained illuminance is the value below which the average illuminance on the assessment plane is not allowed to fall.

With increasing length of service, illuminance is reduced owing to ageing and soiling of lamps, luminaires and room surfaces. To compensate for this, a new system needs to be designed for higher illuminance (value on installation). The reduction is taken into consideration by a maintenance factor: maintained illuminance = maintenance factor x illuminance on installation.

Maintenance factor
The maintenance factor depends on the maintenance characteristics of lamps and luminaire, the degree of exposure to dust and soiling in the room or surroundings as well as on the maintenance programme and maintenance schedule. In most cases, not enough is known at the lighting planning stage about the factors that will later impact on illuminance, so where a maintenance interval of three years is defined, the maintenance factor required is 0.67 for clean rooms and as low as 0.5 for rooms subject to special soiling (e.g. smoking rooms).

The surface on which the illuminance is realised is normally taken as the evaluation plane. Recommended heights: 0.75 m above floor level for office workplaces, max. 0.1 m in circulation areas. The maintained illuminances required for indoor workplaces are defined in DIN EN 12464-1 for different types of interior, task or activity.

Examples:
- circulation areas 100 lx
- office 500 lx
- operating cavity 100,000 lx

For sports lighting, reference planes (at floor/ground level) and illuminance requirements are set out for different types of sport in the harmonized European standard DIN EN 12193. Illuminance is the variable used for planning interior lighting because it is easy to measure and fairly straightforward to compute.

Recommended values:
- local service street 7.5 lx
- main thoroughfare 1.5 cd/m²
- car park 15 lx
Glare limitation – direct glare

**Direct glare** is caused by excessive luminance – e.g. from unsuitable or inappropriately positioned luminaires or from unshielded general-diffuse lamps.

Glare causes discomfort (psychological glare) and can also lead to a marked reduction in visual performance (physiological glare); it should therefore be limited.

**The TI method in street lighting**

Every motorist is aware of the dangers of glare in street lighting and its implications for road safety. Effective limitation of physiological glare is therefore an important requirement for good street lighting.

The method used to limit glare in street lighting is based on the physiological effect of glare and demonstrates the extent to which glare reduces the eye’s threshold of perception.

In outdoor lighting, physiological glare is assessed by the TI (Threshold Increment) method.

The TI value shows in percent how much the visual threshold is raised as a result of glare. The visual threshold is the difference in luminance required for an object to be just perceptible against its background.

Example: Where street lighting is glare-free, the eye adapts to the average luminance of the road L. A visual object on the roadway is just perceptible where its luminance contrast in relation to its surroundings is ΔL₀ (threshold value). Where dazzling light sources occur in the visual field, however, diffuse light enters the eye and covers the retina like a veil. Although the average luminance of the road remains unchanged, this additional “veiling luminance” Lₜ causes the eye to adapt to a higher level L + Lₜ. An object with a luminance contrast of ΔL₀ in relation to its surroundings is then no longer visible.

Where glare occurs, luminance contrast needs to be raised to ΔLₜL for the visual object to be perceptible.

The TI method takes account of all the luminaires in a lighting system which add to the sensation of brightness as well as the brightness of walls and ceilings; it produces a UGR index.

**The UGR method in indoor lighting**

In indoor lighting, psychological glare is rated by the standardized UGR (Unified Glare Rating) method. This is based on a formula which takes account of all the luminaires in a lighting system which contribute to a sensation of glare. Glare is assessed using UGR tables, which are based on the UGR formula and are available from luminaire manufacturers.

The UGR formula is:

\[ UGR = 8 \log \frac{0.25}{L_b} \sum \frac{L^2 \cdot \Omega}{P^2} \]

**Shielding against glare**

To avoid glare due to bright light sources, lamps should be shielded. The minimum shielding angles set out below need to be observed for the lamp luminance values stated.

<table>
<thead>
<tr>
<th>Lamp luminance cd/m²</th>
<th>Minimum shielding angle α</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000 to &lt; 50,000</td>
<td>15°</td>
</tr>
<tr>
<td>50,000 to &lt; 500,000</td>
<td>20°</td>
</tr>
<tr>
<td>≥ 500,000</td>
<td>30°</td>
</tr>
</tbody>
</table>
Glare limitation – reflected glare

Reflected glare refers to the disturbing reflections of lamps, luminaires or bright windows found on reflective or glossy surfaces such as art paper, computer monitors or wet asphalt roads.

Reflected glare can be limited by the right choice and appropriate arrangement of lamps and luminaires. Reflected glare causes the same kind of disturbance as direct glare and, above all, reduces the contrasts needed for trouble-free vision.

Reflected glare on shiny horizontal surfaces (reading matter and writing paper) is assessed using the contrast rendering factor CRF, which can be calculated by special software. For normal office work, a minimum CRF of 0.7 is enough; only work involving high-gloss materials calls for a higher factor.

Reflected glare on VDU screens is the most common cause of complaint. It is effectively avoided where monitors are arranged in such a way that bright surfaces such as windows, luminaires and light-coloured walls cannot be reflected on screens. Where such an arrangement is not possible, the luminance of the surfaces reflected on screens needs to be reduced.

For luminaires, luminance limits have been defined (see table below). These depend on the anti-glare system of the computer monitor and apply to all emission angles above 65° to the vertical all around the vertical axis.

<table>
<thead>
<tr>
<th>VDUs</th>
<th>mean luminance of luminaires and surfaces which reflect on screens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive display VDUs</td>
<td>≤ 1000 cd/m²</td>
</tr>
<tr>
<td>Negative display VDUs with high-grade anti-reflective system</td>
<td>Evidence of test certificate required</td>
</tr>
<tr>
<td>Negative display VDUs with lower-grade anti-reflective system</td>
<td>≤ 200 cd/m²</td>
</tr>
</tbody>
</table>
Marked differences in luminance in the field of vision impair visual performance and cause discomfort, so they need to be avoided. This applies as much outdoors, e.g. in sports facilities or street lighting, as it does in interior lighting.

The luminance of a desktop, for example, should be no less than one third of the luminance of the document. The same ratio is recommended between the luminance of the work surface and that of other areas further away in the room. The ratio of visual task luminance to the luminance of large surfaces further away should not exceed 10:1.

Where luminance contrasts are not sufficiently marked, a monotonous impression is created. This is also found unappealing.

On the roads, good even local luminance distribution is an important safety requirement. It permits timely identification of obstacles and hazards.

Harmonious distribution of brightness, e.g. in offices, can be achieved by lighting geared to the colours and surface finishes of office furnishings. Factors which help create a balanced distribution of luminance in the field of vision include:

- room-related or task area lighting
- use of lighting with an indirect component for better uniformity.
- a ratio of minimum to mean illuminance \((E_{\text{min}}/E)\) of at least 0.7
- adequately high wall, floor and ceiling reflectance.

Indoors, harmonious distribution of brightness is important for visual comfort. On roads, safety is improved by good longitudinal uniformity – which corresponds to harmonious brightness distribution.
Without light we cannot make out objects, without shadow we see objects only as two-dimensional images. It takes directional lighting and modelling to permit 3D projection, to give objects depth.

A bright room with nothing but diffuse lighting and no shadows makes a monotonous impression; the lack of orientation, poor definition of objects and difficulty in gauging distances make us feel uncomfortable.

In contrast, point-like light sources with extremely directional beams produce hard-edged shadows. Such harsh shadow renders virtually everything unrecognizable; it can even cause potentially dangerous optical illusions, e.g. where tools are used, machines are operated or stairs need to be negotiated.

Direction of light and modelling also help define visual ambience. A good ratio of diffuse light (e.g. from indirect lighting components) to directional light (e.g. from direct louver luminaires or downlights) makes for agreeable modelling.

Direction of light is generally defined by daylight entering the room through a window from a particular direction. Excessively deep shadowing, e.g. in front of a writing hand, can be offset by artificial lighting.

In offices where desk arrangements are geared to incident daylight, it is advisable to control daylight incidence by means of window blinds and to use continuous rows of luminaires on separate switching circuits to lighten disturbing shadows.

Where luminaires are arranged parallel to the window wall, the rear row of luminaires can lighten any dark shadows that might occur during the day. As daylight fades, the front row of luminaires near the windows can be partially or fully activated to make up for the loss of natural light.

For certain visual tasks, e.g. for appraising surface characteristics, marked modelling by directional light is required.

In fast ball games such as tennis or squash, adequate modelling is necessary for fast identification of the ball, its flight path and the place where it will land.

To avoid harsh shadows, floodlights are arranged so that each individual beam eliminates the shadow created by others.

Only under directional light from the side can the three-dimensional structure of the wall surface be perceived; in diffuse light it appears smooth.
We experience our surroundings not just as brightness and darkness, light and shadow, but also in colour.

The light colour of a lamp is expressed in terms of colour temperature $T_c$ measured in degrees Kelvin (K). The Kelvin temperature scale begins at absolute zero (0 Kelvin $\approx -273°C$). Colour temperature is used to denote the colour of a light source by comparison with the colour of a standardized “black body radiator”. A black body radiator is an “idealised” solid body, e.g., made of platinum, which absorbs all the light that hits it and thus has a reflective radiance of zero.

When a black body is slowly heated, it passes through gradations of colour from dark red, red, orange, yellow, white to light blue. The higher the temperature, the whiter the colour.

The temperature in K at which a black body radiator is the same colour as the light source being measured is known as the correlated colour temperature of that light source. An incandescent lamp with its warm white light, for example, has a correlated colour temperature of 2800 K, a neutral white fluorescent lamp 4000 K and a daylight fluorescent lamp 6000 K. For reasons of standardization, the light colours of lamps are divided into three groups: dw – daylight white, nw – neutral white and ww – warm white.

<table>
<thead>
<tr>
<th>Numeral</th>
<th>Ra range</th>
<th>Light colour</th>
<th>Colour temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>90 - 100</td>
<td>warm white</td>
<td>&lt; 3300 K</td>
</tr>
<tr>
<td>8</td>
<td>80 - 89</td>
<td>neutral white</td>
<td>3300 - 5300 K</td>
</tr>
<tr>
<td>7</td>
<td>70 - 79</td>
<td>daylight white</td>
<td>&gt; 5300 K</td>
</tr>
<tr>
<td>6</td>
<td>60 - 69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>50 - 59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>40 - 49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lamps with the same light colour can emit light of completely different spectral composition and thus with quite different colour rendering properties. It is not possible to draw conclusions about colour rendering from light colour.

The International Commission on Illumination (CIE) has devised a triangle in which the colours of light sources and body colours can be classified. Depending on brightness, achromatic light (i.e., white, grey or black) is found at $x = y = 0.333$. All the other colours are located around this point. Along the straight line from the achromatic position to the limiting curve (which represents the spectral colours of sunlight) lie the colours of the same hue but differing degrees of saturation. Saturation increases towards the limiting curve. The colour triangle contains all real colours. The curve describes the colours of the “black body radiator” for the given temperatures (in Kelvin).

The way we see colours depends not only on the light colour and colour rendering properties of the lamp. Where light colour departs from the daylight norm, “stored visual standards” enable us – within certain limits – to make subconscious colour corrections.
Light and colour create the “atmosphere” of a room and influence our mood and sense of wellbeing by their “warmth” or “coldness”.

Guaranteeing correct colour perception under artificial light forms a very important part of the lighting designer’s brief. The appearance of coloured objects is affected by the interaction between the colour – i.e. the spectral reflectance – of the objects we see and the spectral composition of the light illuminating them.

In everyday life, we come across surface colours which can differ in appearance depending on how they are illuminated but which we recognize for what they are thanks to “stored visual standards” that are independent of lighting.

For example, we have a stored impression of the colour of human skin in daylight. Where artificial lighting lacks a particular spectral colour or exaggerates certain colours in its spectrum (as is the case with incandescent lamps), skin seen under it may appear a different colour but will still look “natural” because of empirical compensation. For coloured materials for which no “empirical standards” exist, however, colour perception can vary widely.

The effect a light source has on the appearance of coloured objects is described by its colour rendering properties. These are grouped into grades based on the “general colour rendering index” $R_a$.

The colour rendering index indicates how closely the colour of an object matches its appearance under the relevant light source.

To determine the $R_a$ values of light sources, eight defined test colours commonly found in the environment are each illuminated under the reference light source ($R_a = 100$) and then under the source being evaluated. The greater the difference in the appearance of the test colours rendered, the poorer the colour rendering properties of the light source under examination. Under a light source with an $R_a = 100$ rating, all the colours have the same – optimal – appearance as under the reference light source. The lower the $R_a$ index, the poorer the rendering of the surface colours of the illuminated objects.
Light generation by thermal radiators and discharge lamps

In general, lamps generate light either by thermal radiation or by gas discharge, the radiation of which is either directly visible or is made visible by luminescent material.

Incandescent lamps

The incandescent lamp is a thermal radiator which generates light by resistance heating. It consists of a tungsten filament in a glass bulb which, depending on the model, is either evacuated or filled with nitrogen or inert gas (argon).

The inert gas raises the temperature of the tungsten filament and reduces volatilization. This increases the luminous efficacy and, by hindering the blackening of the inside of the glass bulb, counteracts the decline in luminous flux.

The luminous efficacy can be further improved by doubling the coating of the resistance wire.

The mean service life of an incandescent lamp is defined as the length of service of 50% of all lamps under normal working conditions. For general-service tungsten filament lamps this is 1,000 h.

The service life and the luminous flux of an incandescent lamp are influenced by the level of the supply voltage.

Tungsten halogen lamps

A further development of the incandescent bulb is the tungsten halogen lamp, in which the bulb is filled with halogen gas. This ensures that volatilizing tungsten atoms are redeposited on the coil after a "circulating process" and thereby prevents blackening of the bulb.

The main advantages of tungsten-halogen lamps are increased luminous efficacy up to around 25 lm/W, a longer service life, e.g. 2000 hours, constant luminous flux, white light colour and small dimensions.

A distinction is made between tungsten halogen bulbs in high-voltage lamps for 230 V operation and those for low-voltage operation on 6, 12 or 24 V.

Halogen reflector lamps with a metal or specular glass reflector deliver focused beams of light with various beam spreads.

In cool-beam reflector lamps 2/3 of the heat (IR radiation) is diverted backwards through the infrared-permeable specular surface and thereby removed from the light beam. Museum exhibits, for example, are thus protected from excessive heat.

Discharge lamps

Discharge lamps generate light by electric discharge through ionized gas or metal vapour. Depending on the type of gas in the discharge tube, visible light is either emitted directly or UV radiation is converted into visible light by luminescent materials on the inside of the tube.

A distinction is made between low- and high-pressure lamps, depending on the operating pressure in the tube.

To operate, fluorescent lamps require a ballast, which serves mainly to limit the amount of current flowing through the lamp. To ignite a discharge lamp, a starter or igniter is required. This supplies voltage and energy pulses high enough to ionize the gas column (discharge path) and thereby ignite the lamp.

Where electronic ballasts (EBs) are used, luminous efficacy and lamp life are increased. Lamps also start instantly and without flickering and provide constant, steady lighting with no stroboscopic effects. Defective lamps are automatically shut down.

Fluorescent lamps and compact fluorescent lamps operated by appropriate EBs can be dimmer-controlled.

The service life of discharge lamps is generally referred to as the economic life. This takes account of the lamps in a lighting system which are rendered defective e.g. by a broken filament as well as the decrease in luminous flux due to fatigue in the fluorescent material and deterioration of the discharge mechanism. The system luminous flux thus defined must not fall below a certain minimum (80% of output on installation).

Electronic ballasts

- The bulbs of the first incandescent lamps were evacuated, i.e. the tungsten wire of the filament glowed in a vacuum. Tungsten particles volatilizing off the filament settled on the inside of the bulb and made it increasingly dark. The inert gas used to fill bulbs today limits the freedom of movement of the tungsten molecules and thereby reduces the darkening effect.
  - Tungsten
  - Insert gas

- Continuous development and modern manufacturing techniques have led to new, extremely compact lamps such as low-voltage halogen cool-beam specular reflector lamps.
  1 Glass
  2 Cool-beam facet reflector
  3 High-performance burner
  4 Base

- The main advantages of tungsten-halogen lamps are increased luminous efficacy up to around 25 lm/W, a longer service life, e.g. 2000 hours, constant luminous flux, white light colour and small dimensions.

- A distinction is made between tungsten halogen bulbs in high-voltage lamps for 230 V operation and those for low-voltage operation on 6, 12 or 24 V.

- Halogen reflector lamps with a metal or specular glass reflector deliver focused beams of light with various beam spreads.

- In cool-beam reflector lamps 2/3 of the heat (IR radiation) is diverted backwards through the infrared-permeable specular surface and thereby removed from the light beam. Museum exhibits, for example, are thus protected from excessive heat.

- Discharge lamps generate light by electric discharge through ionized gas or metal vapour. Depending on the type of gas in the discharge tube, visible light is either emitted directly or UV radiation is converted into visible light by luminescent materials on the inside of the tube.

- A distinction is made between low- and high-pressure lamps, depending on the operating pressure in the tube.

- To operate, fluorescent lamps require a ballast, which serves mainly to limit the amount of current flowing through the lamp. To ignite a discharge lamp, a starter or igniter is required. This supplies voltage and energy pulses high enough to ionize the gas column (discharge path) and thereby ignite the lamp.

- Where electronic ballasts (EBs) are used, luminous efficacy and lamp life are increased. Lamps also start instantly and without flickering and provide constant, steady lighting with no stroboscopic effects. Defective lamps are automatically shut down.

- Fluorescent lamps and compact fluorescent lamps operated by appropriate EBs can be dimmer-controlled.

- The service life of discharge lamps is generally referred to as the economic life. This takes account of the lamps in a lighting system which are rendered defective e.g. by a broken filament as well as the decrease in luminous flux due to fatigue in the fluorescent material and deterioration of the discharge mechanism. The system luminous flux thus defined must not fall below a certain minimum (80% of output on installation).
Fluorescent lamps
Three-band fluorescent lamps have three or five especially prominent spectral areas in the blue, green and red sectors, which make for good colour rendering properties.

The luminescent coating on the inside of the lamp tube converts the largely invisible UV radiation of the gas discharge into visible light. The chemical composition of the luminescent material determines, among other things, the light colour and colour rendering properties of the lamp.

26 mm-diameter three-band fluorescent lamps have a high luminous efficacy rating and a long service life. As with all other types of fluorescent lamp, the amount of luminous flux they emit depends on the ambient temperature: at –20°C, for example, it falls below 20% capacity, at +60°C below 80%.

Three-band fluorescent lamps with a 16 mm-diameter and shorter tube have even higher luminous efficacy ratings. These T5 fluorescent lamps can only be operated by electronic ballasts (EBS).

Two type series are available: “high luminous efficacy” lamps in 14 W to 35 W power ratings for maximum economy, and “high luminous flux” lamps in 24 W to 80 W ratings for indirect or direct lighting in rooms with very high ceilings. 7 mm-diameter fluorescent lamps with 6 W to 13 W ratings are used in display, furniture and picture lights.

Induction lamps
Induction lamps have no electrodes. The electron flow here is induced by a magnetic field. Because induction lamps have no components which are subject to wear, they attain an average service life of 60,000 operating hours. Induction lamps are available in spherical and – as high-performance fluorescent lamps – flat designs.

LEDs
In an LED, a solid-state crystal is induced to emit light by passing an electric current through it. The type of crystals used have two sections or regions: a region with a surplus of electrons (n-type semiconductor) and a section with a deficit of electrons (p-type semiconductor). When a direct voltage is applied, electrons flow across the junction between the two regions, generating light in the process.

The light thus created has a narrow-band emission spectrum which differs according to the semiconductor material used. White LEDs can be created by additive colour mixing or by luminescence conversion. Their colour temperatures are between 4,000 and 7,000 Kelvin and colour rendering index R around 70.

Among the most important advantages of LEDs are their small dimensions, long life and low failure rates. Also, they emit no IR or UV radiation.

As burning time increases, the luminous flux of fluorescent lamps diminishes and individual lamps fail. These factors determine the system luminous flux, which must not fall below 80% of the luminous flux on installation.
## Lamps

<table>
<thead>
<tr>
<th>No.</th>
<th>Lamp type</th>
<th>Power rating (Watts)</th>
<th>Luminous flux (lumens)</th>
<th>Luminous efficacy (lumens/Watt)</th>
<th>Light colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Linear three-band fluorescent lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T5; 16 mm dia.1)</td>
<td>14 - 35</td>
<td>1250 - 3650</td>
<td>89 - 104</td>
<td>ww,nw,dw</td>
</tr>
<tr>
<td></td>
<td>high luminous efficacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>T5; 16 mm dia.2)</td>
<td>24 - 80</td>
<td>1850 - 7000</td>
<td>77 - 88</td>
<td>ww,nw, dw</td>
</tr>
<tr>
<td></td>
<td>high luminous flux</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>T8; 26 mm dia.</td>
<td>18 - 58</td>
<td>1350 - 5200</td>
<td>75 - 90</td>
<td>ww,nw, dw</td>
</tr>
<tr>
<td></td>
<td>Compact fluorescent lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2-, 4-, 6-tube lamp</td>
<td>5 - 120</td>
<td>250 - 9000</td>
<td>50 - 75</td>
<td>ww,nw</td>
</tr>
<tr>
<td>5</td>
<td>2-tube lamp</td>
<td>18 - 80</td>
<td>1200 - 6000</td>
<td>67 - 75</td>
<td>ww,nw, dw</td>
</tr>
<tr>
<td>6</td>
<td>4-tube lamp</td>
<td>18 - 36</td>
<td>1100 - 2800</td>
<td>61 - 78</td>
<td>ww,nw</td>
</tr>
<tr>
<td></td>
<td>2D-lamp</td>
<td>10 - 55</td>
<td>650 - 3900</td>
<td>65 - 71</td>
<td>ww,nw, dw</td>
</tr>
<tr>
<td></td>
<td>Energy-saving lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Incandescent shape</td>
<td>5 - 23</td>
<td>150 - 1350</td>
<td>30 - 59</td>
<td>ww</td>
</tr>
<tr>
<td>8</td>
<td>standard shape</td>
<td>5 - 23</td>
<td>240 - 1500</td>
<td>48 - 65</td>
<td>ww</td>
</tr>
<tr>
<td>9</td>
<td>230 V tungsten halogen lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>with jacket</td>
<td>25 - 250</td>
<td>260 - 4300</td>
<td>10 - 17</td>
<td>ww</td>
</tr>
<tr>
<td>10</td>
<td>miniature</td>
<td>25 - 75</td>
<td>260 - 1100</td>
<td>10 - 15</td>
<td>ww</td>
</tr>
<tr>
<td>11</td>
<td>with reflector</td>
<td>40 - 100</td>
<td></td>
<td></td>
<td>ww</td>
</tr>
<tr>
<td>12</td>
<td>with base at both ends</td>
<td>60 - 2000</td>
<td>840 - 44000</td>
<td>14 - 22</td>
<td>ww</td>
</tr>
<tr>
<td></td>
<td>Low voltage 12 V halogen lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>with reflector</td>
<td>20 - 50</td>
<td></td>
<td></td>
<td>ww</td>
</tr>
<tr>
<td>14</td>
<td>pin-based lamps</td>
<td>5 - 100</td>
<td>60 - 2300</td>
<td>12 - 23</td>
<td>ww</td>
</tr>
<tr>
<td></td>
<td>Metal-halide lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>with base at one end</td>
<td>35 - 150</td>
<td>3300 - 14000</td>
<td>85 - 95</td>
<td>ww,nw</td>
</tr>
<tr>
<td>16</td>
<td>with base at both ends</td>
<td>70 - 400</td>
<td>6500 - 36000</td>
<td>77 - 92</td>
<td>ww,nw</td>
</tr>
<tr>
<td></td>
<td>High-pressure sodium vapour lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>tubular</td>
<td>35 - 1000</td>
<td>1800 - 130000</td>
<td>51 - 130</td>
<td>ww</td>
</tr>
<tr>
<td></td>
<td>Low-pressure sodium vapour lamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>tubular</td>
<td>18 - 180</td>
<td>1800 - 32000</td>
<td>100 - 178</td>
<td>yellow</td>
</tr>
<tr>
<td></td>
<td>Light emitting diodes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>LED</td>
<td>0.7 - 1.5</td>
<td>18 - 27</td>
<td>13 - 23</td>
<td></td>
</tr>
</tbody>
</table>

Light colour: ww = warm white, nw = neutral white, dw = daylight white  
1) for EB operation only  
2) luminous flux at 35°C
Good lighting depends on the right choice of lamp. Below are the most important lamp types and their specifications.

**Three-band fluorescent lamps (1, 2, 3)**
Three-band fluorescent lamps offer high luminous efficacy coupled with good colour rendering and a long service life. Operated by electronic ballasts (EBs), they achieve an even higher luminous efficacy and longer service life. 16 mm-diameter T5 lamps are designed for EB operation only. With appropriate EBs, all three-band fluorescent luminaires can be dimmer-controlled.

**Compact fluorescent lamps (4, 5, 6)**
Compact fluorescent lamps have the same characteristics as three-band fluorescent lamps. Here too, luminous efficacy, service life and lighting comfort are enhanced by electronic ballasts and dimmer control is possible with appropriate EBs.

**Energy-saving lamps (7, 8)**
Energy-saving lamps have a built-in ballast and a screw base (E14 or E27). They consume as much as 80% less power and have a considerably longer life than incandescent lamps.

**230 V tungsten halogen lamps (9, 10, 11, 12)**
Tungsten halogen lamps for line operation produce an agreeable white light with good colour rendering properties. They have a longer service life than incandescent lamps and achieve higher luminous efficacy. They are fully dimmable and available also as reflector lamps.

**High-pressure sodium vapour lamps (17)**
Very high luminous efficacy and long lamp life make high-pressure sodium vapour lamps a highly economical option for outdoor lighting. They consume only half as much power as high-pressure mercury vapour lamps. Appropriate ballasts and igniters are needed to operate high-pressure sodium vapour lamps.

**Low-pressure sodium vapour lamps (18)**
This type of lamp is noted for having a higher luminous efficacy than any other. Because of its monochromatic beam, it is particularly good at penetrating fog and mist. Low-pressure sodium vapour lamps are used for illuminating port and lock control installations and for security lighting.

**Light-emitting diodes (19)**
LEDs come in numerous shapes and colours. They are extremely small, have a high resistance to impact and a very long service life and emit neither IR nor UV radiation. Given a special fluorescent coating, LEDs produce white light. LEDs are designed for d.c. operation.

<table>
<thead>
<tr>
<th>Colour rendering index</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 to 89</td>
<td>G5</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G9</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G13</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G17</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G23, G24, GX24, 2G7/8</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G9</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G5</td>
</tr>
<tr>
<td>80 to 89</td>
<td>E14, E27</td>
</tr>
<tr>
<td>80 to 89</td>
<td>E14, E27</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G11</td>
</tr>
<tr>
<td>80 to 89</td>
<td>G10</td>
</tr>
<tr>
<td>80 to 89</td>
<td>GR8, GR10, GRY1</td>
</tr>
<tr>
<td>80 to 89</td>
<td>E14, E27</td>
</tr>
<tr>
<td>90 and higher</td>
<td>E14, E27</td>
</tr>
<tr>
<td>90 and higher</td>
<td>G9</td>
</tr>
<tr>
<td>90 and higher</td>
<td>G14, G16, G18</td>
</tr>
<tr>
<td>90 and higher</td>
<td>G10</td>
</tr>
<tr>
<td>90 and higher</td>
<td>GU5,3</td>
</tr>
<tr>
<td>90 and higher</td>
<td>G4, GY6,35</td>
</tr>
<tr>
<td>80 to 89, 90 and higher</td>
<td>G12, G8.5</td>
</tr>
<tr>
<td>80 to 89, 90 and higher</td>
<td>RX7s, FC2</td>
</tr>
<tr>
<td>20 to 39</td>
<td>E27, E40</td>
</tr>
<tr>
<td>20 to 39</td>
<td>BY22d</td>
</tr>
</tbody>
</table>

3) Luminous efficacy increases to 81 - 100 lm/W with EB operation
Luminaires
General requirements and lighting characteristics

Selection of luminaires
Luminaires are selected on the basis of:
• **application**
  interior or exterior luminaire,
• **type and number of lamps**
  incandescent lamp, low-pressure or high-pressure discharge lamp,
• **structural type**
  open or closed luminaire,
• **type of mounting**
  recessed, surface-mounted or pendant luminaire,
• **lighting characteristics**
  such as luminous flux distribution, luminous intensity distribution, luminance distribution and light output ratio,
• **electrical characteristics, including components required for lamp operation**
  electrical reliability, protection class, radio interference suppression, ballast, igniter/starter, etc.,
• **mechanical characteristics**
  mechanical reliability, degree of protection, fire safety features, impact resistance, material properties, etc.,
• **size, construction and design.**

Luminous flux distribution
Total luminous flux \( \Phi_L \) is the sum of the partial luminous flux emitted in the lower half \( \Phi_U \) and upper half \( \Phi_O \) of the luminaire. Luminaires are categorized by the amount of lower luminous flux they emit and assigned to groups A to E as defined in DIN 5040.

For most outdoor applications, luminaires for direct lighting are normally the preferred option. However, for decorative lighting in pedestrian precincts, parks etc., luminaires with a small indirect lighting component can be usefully employed to highlight trees or building façades.

Lighting materials
In order to direct, distribute or filter the luminous flux of lamps, two basic kinds of “lighting materials” are used:
• **reflective materials**
• **translucent light-transmitting materials.**
Reflective materials are used to reflect as much light as possible. They can be subdivided into materials for:
• **directional reflection**
  e.g. specular reflectors and louvers of highly polished anodised aluminium; coupled with precise specular design, these optical controllers make for finely defined beams and luminance control.
• **mixed reflection**
  e.g. satinized specular louvers; in contrast to matt materials, the surface of these optical controllers has a more pronounced directional component for “defined” shielding conditions.
• **diffuse reflection**
  e.g. matt specular louvers or reflectors and louvers with enamelled surfaces; the luminaire face is clearly visible owing to its higher luminance.
Luminous intensity distribution
The three-dimensional distribution of the luminous intensity of a luminaire is indicated by the luminous intensity distribution model. It can be shown for various planes in polar diagrams (IDCs). To facilitate comparison, the intensities relate to 1000 lm of the lamps in the luminaire and are expressed accordingly as cd/klm (candelas per kilolumen).

The shape of an IDC shows whether the luminaire has a narrow- or wide-angle, symmetrical or asymmetrical beam.

Intensity distribution curves are usually established under standardized luminaire operating conditions using a computer-controlled rotating mirror goniophotometer. They provide the basis for planning interior and exterior lighting.

Luminance distribution and shielding
To assess the glare produced by interior luminaires, it is necessary to know their mean luminance at angles critical for glare. Mean luminance is the quotient of luminous intensity and the effective luminous area perceived by observers.

In street lighting, glare depends, among other things, on the size of the luminous area and the light emitted by the luminaires. Luminous intensity at critical beam angles is limited by deflection within the optical control system.

Directionally translucent materials (such as glass and plastics) are also employed for optical control by harnessing their capacities for refracting and reflecting light. When a beam of light passes from one optical medium into another, it changes direction according to the angle of incidence and thus undergoes optical control.

Light output ratio $\eta_{LB}$
This is an important quantity for assessing the energy efficiency of a luminaire and its lighting performance. Light output ratio $\eta_{LB}$ is the ratio of the luminous flux radiated by a luminaire to the sum of the luminous fluxes of its lamps, measured under specific operating conditions.

Those conditions define the normal operating position of the luminaire and a normal ambient temperature of 25°C.

Although a track-mounted general-diffuse luminaire has a higher light output ratio $\eta_{LB}$ than a shielded specular luminaire, it also causes more glare. Specular louver luminaires, for instance, produce substantially higher illuminance on the working plane. Light output ratio is thus not a reliable yardstick for illuminance on the working plane.
Luminaires

Electrical characteristics, ballasts

Class of protection
Luminaires are divided into three classes of protection according to the protective measures taken against electric shock:

- **Class I**: Touch-accessible metal components are connected to the protective conductor. The protective conductor terminal is indicated by the symbol.

- **Class II**: Live components are provided with additional protective insulation. Connection to the protective conductor is not allowed. Symbol.

- **Class III**: Luminaires are operated on protective extra-low voltages (< 42 V) that present no danger to human beings. Symbol.

Degrees of protection IP
The mechanical design of luminaires must be such that they are adequately protected against the ingress of foreign bodies and moisture. The degree of protection is indicated by the IP (Ingress Protection) numbering system.

The first numeral indicates the degree of protection against foreign bodies, the second numeral protection against water.

An IP 20 luminaire, for example, is protected against the ingress of foreign bodies > 12 mm, but not against moisture. A luminaire designed for use in damp interiors, with a degree of protection of IP 65, is protected against the ingress of dust and against jets of water.

Electromagnetic compatibility
Electrical equipment and electronic circuits can send out intended or unintended high-frequency electromagnetic signals, which are either beamed through the air or fed into cables. Such equipment is also susceptible to external interference which can prevent it from operating normally. Growing use of electronic equipment makes it vital to ensure that this kind of cross-interference is suppressed. Luminaires for discharge lamps are potential sources of such interference.


Compliance with the relevant standards is evidenced by the EMZ symbol of the VDE test and certification institute.

- The luminaires are examples of different IP degrees of protection and show that the higher degrees of protection require much more sophisticated mechanical solutions.

**IP 11**
- foreign bodies > 50 mm
- drops of water

**IP 20**
- foreign bodies > 12 mm
- unprotected

**IP 23**
- foreign bodies > 12 mm
- spraywater

**IP 33**
- foreign bodies > 2.5 mm
- spraywater

**IP 40**
- foreign bodies > 1 mm
- unprotected

**IP 44**
- foreign bodies > 1 mm
- splashwater

**IP 50**
- dust-protected
- unprotected

**IP 54**
- dust-protected
- splashwater

**IP 65**
- dustproof
- jetwater

**IP 66**
- dustproof
- floodwater

- Luminaires need to be designed for conformity with one of the three electrical classes of protection against electric shock.
Fire safety
When selecting luminaires, consideration should be given to the fire-resistance of the mounting surfaces and the luminaire surroundings. DIN VDE 0100 Part 559 stipulates that luminaires with the symbol \( \text{F} \) are suitable for direct installation on building materials that remain dimensionally stable and stationary at temperatures up to 180 °C. Luminaires without a fire protection symbol may only be directly installed on non-flammable building materials such as concrete.

At locations exposed to fire hazards, however, where highly flammable materials such as textile fibres etc. may be deposited on luminaires, only models with the \( \text{F} \) symbol may be installed. Such luminaires are designed so that the temperature of their surfaces does not rise above the stipulated threshold temperature. Luminaires for direct mounting in or on furnishings, e.g. furniture, must bear the \( \text{W} \) symbol, depending on the material of the mounting surface.

Impact resistance
Luminaires for use in sports facilities in which ball games are played must be impact-resistant and be marked with the symbol indicating suitability for sports facility use. This also applies to luminaire accessories and mounting components.

Energy efficiency of luminaires
Most of the electrical energy consumed is consumed by the lamp and its operating gear. To indicate the energy consumption of the ballast/lamp system, an energy classification system has been introduced at European level (Directive 2000/55/EC on energy efficiency requirements for ballasts for fluorescent lamps).

The EEI (Energy Efficiency Index) distinguishes between seven classes of ballast: A1 Dimmable electronic ballasts (EBs) A2 Electronic ballasts (EBs) with reduced losses A3 Electronic ballasts (EBs) B1 Magnetic ballasts with very low losses (LLBs) B2 Magnetic ballasts with low losses (LLBs) C Magnetic ballasts with moderate losses (CBs) D Magnetic ballasts with very high losses (CBs).

The sale of Class D ballasts has been prohibited since 21 May 2002; Class C ballasts must be withdrawn from the market by 21 November 2005 at the latest.

Ballasts
One thing all discharge lamps have in common is their negative current/voltage characteristic: a current supplied at constant voltage reaches an intensity that would destroy the lamp. Hence the need for discharge lamps to be operated by ballasts. These serve to limit the current and, in combination with e.g. starters, to ignite the lamps.

Growing energy awareness has prompted major technological improvements in ballasts, especially ballasts for fluorescent lamps. The conventional ballast (CB) has now been superseded by the (inductive) low-loss ballast (LLB) and the electronic ballast (EB). Electronic ballasts convert 230 V/50 Hz line voltage into a high-frequency a.c. voltage of 25 to 40 kHz, which lowers the power intake of a 58 W lamp to around 50 W while maintaining virtually identical luminous flux. The power required by a lamp/EB system in our example is reduced to 55 W, which represents a 23% saving in comparison with the CB system. Use of efficient, energy-saving ballasts is encouraged by measures taken by the EU. Even today, more than 40% of new and refurbished lighting systems with fluorescent – including compact fluorescent – lamps are already fitted with EBs.

In addition to the considerable energy savings achieved, making for short EB pay-back times of only a few years, high-frequency EB operation of fluorescent lamps and a growing number of other discharge lamps by EB has other advantages:

Advantages of electronic ballasts EB
• low ballast losses
• higher lamp luminous efficacy
• optimal transformation of wattage into light
• reduced operating costs
• reduced air-conditioning costs
• no starter, no p.f. correction capacitor
• can be run on a.c. or d.c. current
• constant lamp performance over wide voltage range
• suitable for emergency lighting
• low magnetic induction interference
• use in medical examination rooms
• defective lamps automatically shut down (fire protection)
• approx. 50% longer lamp life
• enhanced lighting comfort and quality
• dimmer control possible (special EB)
Luminaires
Operating devices, regulation, control, BUS systems

Transformers
Operating low-voltage tungsten halogen lamps requires transformers with an output voltage of 6 V, 12 V or 24 V.

A distinction is made between conventional and annular core transformers; the difference is less a matter of power dissipation than of size.

Additional features provided by electronic transformers include automatic shutdown in open circuit, ability to withstand short circuits, and gentle starting for longer lamp life.

Advantages of electronic transformers
- compact size
- low weight
- low power dissipation
- low internal resistance
- no noise generation
- high efficiency
- overload and overheating prevented by power control without lamp deactivation
- non-encapsulated, therefore repairable if defective
- soft starting - no current peaks on activation
- electronic protection against short-circuiting

Transformers for low-voltage tungsten halogen lamps turn the 230 V supply voltage into a lamp-operating voltage of 6, 12 or 24 V. On the secondary side are correspondingly high currents requiring a significant increase in the cross-section of the transformer winding and of the lamp connection cable.

To compensate the inductive reactive power of conventional (CB) and low-loss ballasts (LLB), luminaires with fluorescent lamps are fitted with a capacitor parallel to the line connection (230 V).

P.f. correction capacitors
P.f. correction capacitors serve to improve the power factor. They reduce the inductive reactive power of the ballasts (chokes) that contributes to the load on the electrical equipment, e.g. leads, cables, transformers and switches. Power utilities stipulate that p.f. correction capacitors need to be used in luminaires with discharge lamps.

P.f. correction capacitors must bear the symbol F (flameproof) or FP (flame-and explosion-proof), display a test symbol from a recognised testing agency and be equipped with a discharge resistor.

P.f. correction capacitors are not required where EBs are used.

Starters and igniters
Starters for fluorescent lamps complete or open the preheating current circuit of a fluorescent lamp and thereby initiate the ignition process. A distinction is made between universal and fused rapid starters. Starters are not required where EBs are used.

Metal halide lamps and high-pressure sodium vapour lamps need a starting voltage pulse of the order of 1 to 5 kV. Igniters with special electronic switches are thus used to ignite high-pressure discharge lamps.

For the immediate hot re-ignition of extinguished metal halide or high-pressure sodium vapour lamps, igniters with voltages considerably higher than 5 kV are required.
Low-voltage installation
Because of their low operating voltages, low-voltage installations constitute no immediate hazard to human beings. It needs to be borne in mind, however, that the stepped-down voltage gives rise to very high currents. (Example: lamp 230 V, 100 W; current I = 0.43 A; lamp 12 V, 100 W; current I = 8.33 A).

If cables, contacts, terminals or switches are not adequately dimensioned, these high currents can cause overload. To avoid fire hazards in such cases, special installation requirements need to be observed.

Low-voltage plug-in systems, with plugs, couplings and cables, have a proven track record here.

Regulation and control
Lighting regulation and control play a central role in modern building service management. As well as the energy savings they permit, they are increasingly appreciated for the convenience they provide and the motivational boost delivered by dynamic lighting.

Lighting can be adjusted according to the amount of natural light available or the position of the sun (daylight control or regulation), according to whether the room is in use (presence detection) or according to the lighting atmosphere required (e.g. RGB control).

Dimmer control of GLS or 230 V tungsten halogen lamps presents no problems with leading phase-angle control dimmers. Low-voltage tungsten halogen lamps operated on a conventional or annular-core transformer need a special dimmer geared to the behaviour of the transformer in dimming operations.

Lamps used in combination with electronic transformers can only be regulated by special leading or lagging phase-angle control dimmers, and attention should be paid to the manufacturer's information.

Controllable EBs permit infinite flicker-free adjustment of fluorescent lamps down to 1% luminous flux.

DALI – digital lighting management
DALI (Digital Addressable Lighting Interface) is an intelligent lighting management system specifically developed to meet the requirements of modern lighting technology. Easy to use, cost-efficient and designed for use with interface modules permitting integration in building management systems with EIB (European Installation Bus) or LON (Local Operating Network) circuitry.

DALI controls lighting through all DALI components and can address each appliance individually. It can assign each EB (= luminaire) equally, for example, to as many as 16 groups, define 16 lighting production attributes for each individual fitting or dim all EBs together in one synchronized operation.

The members of AG-DALI, the DALI working group in the German electrical and electronic manufacturers' association ZVEI, include leading European and US manufacturers of electronic ballasts and lighting control and regulation systems.

Central management of building installations
- Bus systems
The increasing complexity of building technology and the control and monitoring of all building installation and service systems, e.g. heating, air-conditioning, alarm and security systems, lighting, window blind control etc., require a new approach to building management that incorporates all the individual systems – including lighting – in an intelligent control system.

Microelectronics and data transmission techniques make it possible for all the necessary system groups to "communicate" with each other via a shared bus network.

Information from sensors (e.g. photovoltaic barriers, infrared receivers, wind gauges, brightness sensors) is conveyed by the bus network. The appropriate assignment of sensors (receivers) and actuators (switches) permits a wide variety of functions to be programmed for control and regulation.

Dimming thermal radiators: correlation of wattage and luminous flux.
A wide variety of luminaires are available to cater to the diverse technical and design requirements of the broad range of lighting applications.

The examples shown on these two pages are only a small selection. In particular, they do not include luminaires designed for special applications, such as tunnel luminaires, building security luminaires, luminaires for explosive atmospheres, air-conditioning luminaires and clean room luminaires.

More information about luminaire systems and manufacturers is available on the internet at www.licht.de.
Direct/indirect recessed luminaires

Downlights with symmetrical beam (left) and asymmetrical beam (right)

Direct/indirect standard office luminaire with desktop luminaire

Direct/indirect standard domestic luminaire with tabletop luminaire

Wall luminaires as surface-mounted luminaire (left) and as recessed luminaire (right)

Escape sign luminaire for identifying escape route

Bollard luminaire

Recessed ground luminaire

Post-top luminaire (left)

Light stela (right)
**Lighting planning**

**Interior lighting**

Interior lighting systems need to conform to the relevant standards.

For planning a lighting system, the following are needed:

- ground plan and sectional views of the rooms, with room dimensions
- details of ceiling construction,
- colours and reflectance of ceilings, walls, floors and furnishings
- purpose of the room, proposed visual tasks
- location of work zones
- arrangement of furniture and/or machines
- operating conditions, e.g. temperature, humidity, exposure to dust

Appropriate light sources and luminaires should be selected on the basis of these data. After the number of lamps has been calculated for the illuminance required, the number and arrangement of luminaires can be determined. Lighting, mounting and maintenance factors, and architectural considerations all play an important role in the planning process.

The architect’s preferences for certain types of luminaire and luminaire arrangements need to be balanced against an appreciation of lighting technology and ergonomics.

**Illuminance levels on working plane, floor, ceiling and walls**

Illuminance levels on working plane, floor, ceiling and walls can be computed and displayed as isolux curves by lighting planning software.

**Planning software computes the illuminance at a large number of points in the room and produces a graphic display of the results.**

Utilance is a function of the luminous flux distributed by the luminaire, the geometry of the room and the reflectance of room surfaces.

The coefficient of utilization $\eta_B$ includes the light output ratio $\eta_{LB}$ and the utilance $\eta_R$. Extensive tables of coefficients of utilization $\eta_B$ are supplied by luminaire manufacturers.

**Lighting planning by the lumen method**

This method is described in "Projekterung von Beleuchtungsanlagen nach dem Wirkungsgradverfahren" (Planning lighting systems by the lumen method), which is published by the Deutsche Lichttechnische Gesellschaft eV (LiTG) and also includes utilance tables for a number of standard luminaires.

The number of luminaires required for any desired illuminance can be calculated using the following formula:

$$n = \frac{E \cdot A}{z \cdot \Phi \cdot \eta_B \cdot WF}$$

**Key**

- $n$ number of luminaires
- $E$ illuminance required
- $A$ area or partial area of room
- $z$ number of lamps per luminaire
- $\Phi$ light output ratio
- $\eta_B$ coefficient of utilization
- $WF$ maintenance factor

**The computer simulation of the illuminated square and adjacent street at night provides a realistic view of the installation in operation – enabling the lighting designer to check his or her work.**
Planning software enables computed results, such as the illuminance values on the evaluation plane, to be viewed in the form of a grey-tone diagram.

Input and the interpretation of results. Computer graphics provide a realistic image of the lighting system.

In addition to furnishing the technical documentation for a lighting project, programs can also draw up a list of materials together with a breakdown of the luminaires of each type required in the room, including a descriptive text.

Numerous help functions are available at the touch of a key; graphic displays facilitate the input and the interpretation of results. Computer graphics provide a realistic image of the lighting system.

Planning lighting with computer software

The lumen method is used to calculate the number of luminaires required for a given mean illuminance. The illuminance calculations at different points in the room are performed by computer. Special software is available for this purpose.

Using menu-driven inputs, lighting planning software provides a complete set of lighting calculations - from initial rough outline to fully documented, comprehensive proposal.

Another photorealistic computer image: here, the impact of lighting on a car park at night.

Street lighting

The purpose of street lighting is to improve road safety during darkness. It can only do so, however, if it meets key lighting criteria.

This entails satisfying the minimum requirements needed to enable drivers to make out shapes and movements at a safe distance and thus respond appropriately to the presence of people and objects in the traffic area.

The challenge for the lighting planner is to meet the requirements laid down in road safety standards and regulations for luminance, longitudinal and overall uniformity and glare limitation. The result should be a clear “image” of the road ahead.

Capital expenditure, operating and maintenance costs need to be low to ensure an economical lighting system. And the luminaire arrangement, the types of luminaires and the lamps used in them need to be selected to produce an optimal solution for the geometry of the road.

As for the choice of appropriate luminaires, the most economical options are luminaires with specular optical systems for high-pressure discharge lamps.

To calculate the average roadway luminance and uniformity of luminance, it is necessary to know the luminous intensity distribution of the luminaires, the luminous flux of the lamps, the geometry of the installation and the reflective properties of the road surfaces. The figures for the last parameter can be taken from standard road surface tables or obtained by measurement using a road reflectometer.
Lighting costs

Whether new systems are being installed or old systems refurbished, energy consumption and cost are important criteria for lighting system planning. Project planning thus needs to include an energy-balance calculation and an economic feasibility study.

Cost comparisons only make sense where the quality, service life, serviceability and maintenance requirements of luminaires as well as the availability of spare parts and compliance with lighting quality features are comparable and guaranteed.

Appropriate, precise planning, competent selection of lamps, operating devices and luminaires, and an optimal luminaire arrangement are prerequisites for a lighting system which will save energy and reduce costs.

New innovative techniques and computer-aided planning can help here. Technological progress has brought numerous improvements in modern lamps, luminaires and lighting techniques, e.g. increased luminous efficacy in fluorescent lamps, reduced power dissipation in ballasts, improved light output ratios, increased coefficients of utilization due to more practical luminaire system design and more precise lighting planning methods.

Different lighting systems can be compared by applying the cost formula shown above.

\[
K = n_1 \left[ \frac{k_1}{100} \cdot K_1 + \frac{k_2}{100} \cdot K_2 \right] + n_1 \left[ t_B \cdot a \cdot P \right] + n_1 \left[ \frac{t_B}{t_L} \left( K_3 + K_4 \right) + \frac{R}{n_2} \right]
\]

Capital costs

Energy costs

System maintenance

Key:
- \( K \): Total annual costs
- \( K_1 \): Cost of one luminaire
- \( k_1 \): Service of capital for \( K_1 \) (interest and depreciation) in %
- \( K_2 \): Costs of installation materials and mounting per luminaire
- \( k_2 \): Service of capital for \( K_2 \) (interest and depreciation) in %
- \( R \): Cleaning costs per luminaire and year
- \( n_1 \): Total number of lamps
- \( n_2 \): Number of lamps per luminaire
- \( K_3 \): Price of one lamp
- \( K_4 \): Cost of replacing one lamp
- \( P \): Power consumption of one lamp incl. ballast in kW
- \( A \): Cost of electricity per kWh incl. pro rata provision costs (basic charge)
- \( t_B \): Rated service life of lamp in h
- \( t_L \): Annual operating hours
In lighting engineering, measurements are taken to:
• check lighting proposals,
• check the condition of existing lighting systems to determine whether maintenance or refurbishment are required,
• compare different lighting systems.

Standards and regulations set out stipulations to ensure that measurement and evaluation methods are standardized.

Important variables are:
• illuminance $E$, e.g. as horizontal illuminance $E_h$, as vertical illuminance $E_v$, as cylindrical illuminance $E_z$ or semi-cylindrical illuminance $E_{hz}$,
• luminance $L$, e.g. in street lighting, tunnel lighting or interior lighting,
• reflectance $\rho$, e.g. of ceilings, walls, floors, in workplace interiors and sports halls,
• the reflective properties of road surfaces, e.g. in street and tunnel lighting,
• line voltage $U$ and/or ambient temperature $t_a$ for lighting systems with lamps whose luminous flux is dependent on the service voltage and/or the room or ambient temperature.

In practice, the variable measured most frequently is illuminance. For this, instruments with a relative spectral sensitivity comparable to that of the human eye $V(\lambda)$ are used. Oblique incident light needs to be measured in line with the cosine law.

When preparing photometric procedures, the following need to be established:
• geometric dimensions of the lighting system,
• type of system/nature of interior and activity,
• variables to be measured and location of measuring points,
• general condition of the system, e.g. age, date of last cleaning and last lamp replacement, degree of soiling.

Before measurements are taken, lamps should be left on long enough for the system to reach a steady state and interference by extraneous light (e.g. daylight influencing interior or vehicle lighting, shop window or advertising lighting influencing outdoor lighting) should be eliminated. Interference due to obstacles or shadows cast by persons taking measurements must also be avoided.

For illuminance measurements, the ground or floor area of the installation in question should be divided into – preferably square – patches of equal size. To avoid obtaining only maximum values, e.g. directly under luminaires, the measurement grid thus formed should not reflect the modular dimensions of the luminaire arrangement. However, symmetrical features of lighting system, room or outdoor space can be usefully employed to reduce the number of measurements required. Measurements are presented in tables. A graphic representation of illuminances in isolux curves is obtained by joining up points of equal illuminance.

To determine mean illuminance $\bar{E}$, the individual measurements are added together and divided by the number of points at which measurements are taken.

The uniformity of illuminance $g_1$ is the quotient of the lowest illuminance value ascertained $E_{\text{min}}$ and the mean illuminance $\bar{E}$ calculated.

Uniformity $g_2$ is the ratio of $E_{\text{min}}$ to the highest illuminance value ascertained $E_{\text{max}}$.

A record of each measurement should be kept, documenting, for example, not just the values themselves but also the ambient conditions, details of lamps, luminaires and the geometry of the lighting system.

<table>
<thead>
<tr>
<th>Class</th>
<th>Quality</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>high</td>
<td>precision photometry</td>
</tr>
<tr>
<td>B</td>
<td>medium</td>
<td>industrial photometry</td>
</tr>
<tr>
<td>C</td>
<td>low</td>
<td>rough photometry</td>
</tr>
</tbody>
</table>
Much of the progress achieved in lighting engineering is due to new and further developments in discharge lamp technology. One example is the advent of the compact fluorescent lamp. A more economical alternative to the incandescent lamp, this electronically operated light source couples greater economy with enhanced lighting comfort.

For general lighting purposes, the following types of discharge lamps are used:
- fluorescent lamps, including compact fluorescent lamps
- high-pressure mercury vapour lamps
- metal halide lamps
- high-pressure sodium vapour lamps
- induction lamps

Comparison of the total energy consumed in the manufacture and operation of different lamps for a specific amount of light clearly shows the superiority of modern discharge lamps over incandescent lamps. Their efficiency is also underlined by the fact that more than 80% of all the artificial light generated in Germany is produced by discharge lamps - although they constitute only 50% of all the lamps in use.

The use of incandescent lamps instead of discharge lamps would require a more than 5-fold increase in power station output for light generation. The positive contribution discharge lamps make to reducing pollution more than outweighs their environmental impact.

**Recycling discharge lamps**

In contrast to incandescent or tungsten halogen lamps, energy-saving lamps, fluorescent lamps and other discharge lamps contain environmentally relevant substances. At the end of their useful life, they thus become hazardous waste and need to be assigned to experts for disposal: it is illegal to dispose of them as domestic waste or glass waste.

For the disposal of small quantities, users should turn to local waste collection points or consult waste management authorities. For larger quantities, it is worth contacting a special lamp recycling company directly.

For further information, contact AG LV im ZVEI Stresemanallee 19 60596 Frankfurt am Main Germany

**Light immissions**

Light immissions are the disturbing effect of exterior lighting systems on adjacent residential areas. A distinction is made between brightening and glare.

Brightening is defined as unpleasant increased illumination of living areas (measured in vertical illuminance Ev at the window).

Glare is a form of visual disturbance caused by bright nearby streetlamps or floodlights (measured in luminaire luminance perceived by the observer).

The basis on which these measurements are made is described in the LI TG publication “Messung und Beurteilung von Lichtimmissionen” (Measurement and assessment of light immissions).
Order Form

Please indicate number of booklet(s) required. Prices given include postage. (e = available in English, E = available only as pdf-file, download at www.licht.de):

<table>
<thead>
<tr>
<th>Booklet No / Title</th>
<th>Qty</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lighting with Artificial Light (7/04)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>2. Good Lighting for Schools and Educational Establishments (7/03)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>3. Good Lighting for Offices and Industry (1/03)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>4. Good Lighting for Health Care Premises (1/04)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>5. Good Lighting for Retail and Leisure Facilities (4/01)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>6. Good Lighting for Hotels and Restaurants (4/99)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>7. Lighting for Schools and Educational Establishments (4/00)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>8. Lighting Quality with Photometric Tools (5/03)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>9. Prestige Lighting (8/97)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>10. Notbeleuchtung, Sicherheitsbeleuchtung (4/00)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>11. Good Lighting for Hotels and Restaurants (4/00)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>12. Lighting Quality with Photometric Tools (5/03)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>13. Light for Islands and Ships (6/00)</td>
<td>1</td>
<td>9,- €</td>
</tr>
<tr>
<td>14. Lichtforum (free of charge)</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Books 13 and 15 are out of print.

Literature, acknowledgements for photographs

- Standards
  - DIN EN 1838: Lighting applications – Emergency lighting
  - DIN EN 12193: Light and lighting - Sports lighting
  - DIN EN 12464: Light and lighting - Lighting of work places
    Part 1: Indoor work places
  - DIN EN 12665: Light and lighting - Basic terms and criteria for specifying lighting requirements
  - DIN EN 13201: Street lighting
  - DIN 5032: Photometry
  - E DIN 5035-3: Artificial lighting - Lighting of health care premises
  - DIN 5035-6: Artificial lighting - Measurement and evaluation
  - DIN 5035-7: Artificial lighting, Part 7: Lighting for interiors with visual display work stations

- LiTG - Deutsche Lichttechnische Gesellschaft e.V.
  - Publikation 3.5:1988 „Projektierung von Beleuchtungsanlagen nach dem Wirkungsgradverfahren“ (Planning lighting systems by the lumen method)
  - Publikation 13:1991 „Kontrastwiedergabefaktor CRF - ein Gütemerkmal der Innenraumbeleuchtung“ (Contrast rendering factor CRF – an interior lighting quality factor)
  - Publikation 15:1997 „Zur Einwirkung von Außenbeleuchtungsanlagen auf nachtaktive Insekten“ (Impact of exterior lighting systems on nocturnal insects)
  - Publikation 17:1998 „Straßenbeleuchtung und Sicherheit“ (Street lighting and safety)
  - Publikation 18:1999 „Verfahren zur Berechnung von horizontalen Beleuchtungsstärkereihe für Innenräume“ (Methods for calculating horizontal illuminance in interiors)
  - Publikation 20:2003 „Das UGR-Verfahren zur Bewertung der Direktblendung der künstlichen Beleuchtung in Innenräumen“ (The UGR method of assessing direct glare from artificial lighting in interiors)

- www.litg.de

- LiTG, Burggrafenstraße 6, 10787 Berlin

- Acknowledgements for photographs
  - Photos 1, 2, 3: Internationale Lichterndschau, NL - 5600 Eindhoven
  - Photo 57: K.H. Laux, 50933 Köln

All other photographs, 3D visualizations and illustrations: Fördergemeinschaft Gutes Licht (FGL)
Fördergemeinschaft Gutes Licht

From  Name, Company, Office
c/o  Address or P.O. Box
city  postal code

Postcard

Order Form

Please indicate number of booklet(s) required. Prices given include postage. (e = available in English, E = available only as pdf-file, download at www.licht.de):

<table>
<thead>
<tr>
<th>Booklet No / Title</th>
<th>Qty</th>
<th>Price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lighting with Artificial Light (7/04)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>2. Good Lighting for Schools and Educational Establishments (7/03)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>3. Good Lighting for Safety on Roads, Paths and Squares (3/00)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>4. Good Lighting for Offices and Office Buildings (1/03)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>5. Good Lighting for Trade and Industry (4/99)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>6. Good Lighting for Sales and Presentation (2/02)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>7. Good Lighting for Health Care Premises (4/04)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>8. Good Lighting for Sports and Leisure Facilities (9/01)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>9. Prestige Lighting (8/97)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>10. Notbeleuchtung, Sicherheitsbeleuchtung (4/00)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>11. Good Lighting for Hotels and Restaurants (4/00)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>12. Lighting Quality with Electronics (5/03)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>13. Ideen für Gutes Licht zum Wohnen (9/99)</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>14. Urban image lighting</td>
<td>1</td>
<td>9.00</td>
</tr>
</tbody>
</table>

13 and 15 are out of print

Please fill in address on back of postcard

This booklet is No. 1 in the series Information on Lighting Applications published by Fördergemeinschaft Gutes Licht (FGU) to provide information on good artificial lighting.

The postcards on this page can be detached and used for ordering these books. Orders can also be placed by e-mail (fgl@zvei.org) or via the Internet (www.licht.de).

An invoice will be sent with the book(s) ordered.

Impressum

This booklet is No. 1 in the series.

Information on Lighting Applications published by Fördergemeinschaft Gutes Licht (FGU) to provide information on good artificial lighting.

The titles and numbers of all the booklets in this series are shown on the page opposite.

The postcards on this page can be detached and used for ordering these books. Orders can also be placed by e-mail (fgl@zvei.org) or via the Internet (www.licht.de).

An invoice will be sent with the book(s) ordered.
Fördergemeinschaft Gutes Licht (FGL) provides information on the advantages of good lighting and offers a great deal of material on 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 16 in this series of publications are designed to help anyone 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 focusing on topical lighting issues and trends. It is published at irregular intervals.

www.licht.de
FGL is also on the internet. Its website

www.licht.de
features a Private Portal and a Pro Portal offering tips on correct lighting for a variety of domestic, commercial and industrial “Lighting Applications”. 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 FGL members provide a direct route to manufacturers.

“Publications” in an online shop and “Links” for further information round off the broad spectrum of the FGL light portal.

Booklets 13 and 15 are out of print.