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LEDs: Basics - Applications - Effects

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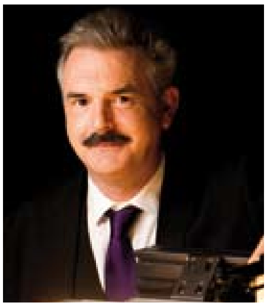


Editorial

Dear Reader
You have before you a new edition of the licht.wissen booklet on LED technology. I am delighted to have been given the opportunity to introduce you to this fascinating topic. Anyone who has worked in lighting technology in recent years has experienced a revolution in the field of light sources. The light-emitting diode (LED) was first introduced into niche products such as high-mounted brake lights at the end of the 1990s. Developers took great delight in boasting that they were using the brightest red LEDs with a luminous flux of one to three lumens. Nowadays it is easy to generate the luminous flux of a 100W incandescent lamp using just a few LED chips.

The development of LEDs is a great success story, as they have now become the most efficient and durable artificial light source in human history and are increasingly overcoming their specific shortcomings, such as those relating to light quality. The spectrum extends from the original, saturated LED colours to various white shades, ranging from cool-white with low colour rendering to warm-white with high colour rendering. A new dimension of lighting has been opened up by the wide spectral adaptability of LEDs (for example through RGBW mixing) and their dynamic control. Application aspects range from non-visual effects and the right light for certain activities through to the different facets of "Human Centric Lighting". In this licht.wissen booklet you will find a multitude of indoor and outdoor application possibilities. Light for seeing, watching, learning, buying, feeling healthy and many other topics. The basics principles behind LED technology are also worthy of attention.

The system aspect has been prominent in the development of LED luminaires. As a semiconductor light source, LEDs require electronic controls and good heat dissipation. As a "cold" light source, they permit the creation of innovative optical systems with highly efficient light control on the one hand while opening up new design possibilities in lighting technology on the other. Although retrofits still dominate the market today, more and more LED solutions are being developed that no longer use the existing sockets developed for other light sources. Despite – and indeed because of the many new possibilities – a multitude of research questions into the basics and application of LED technology have arisen. This booklet contains many such examples, including those relating to very practical aspects of lighting planning.

I hope you that you enjoy reading and learning, and that the articles arouse and increase your interest in - and knowledge about - LED technology for many future applications.

Regards,

Prof. Dr. Cornelius Neumann
Light Technology Institute Karlsruhe

[cover] Inside LED luminaires, most LEDs are soldered onto live conductors.

[01] LED lighting is extremely versatile and has significantly expanded the range of options available to lighting designers – while offering the highest light quality.

Licht-Spezial

02

03

04

LEDs – The light source of the 21st century

We are now living in the Luxopocene era, the age of the luminous human, as Mathias Wambsganß wrote in the 2017 Future Report. But how can the future of lighting technology be made sustainable, controllable and flexible? The answer is: with LEDs, which are now regarded as the light source of the 21st century.

Since the beginning of the 2000s, LEDs – in the basic colour white – have become an integral part of general lighting solutions. Initially only suitable for smaller visual tasks, the light yields of these semiconductor LED light sources have increased rapidly, allowing them to be deployed in all lighting areas. They are now even exceeding the output capacities of previous light sources – from torches through to general room lighting and high-power spotlights, with significantly better consumption values and much greater flexibility. As in all economic sectors, a high level "battle" is being waged in the field of technology, too. The luminous efficacy and luminous flux values were the initial "battlefields"; these were followed later by the service life of the lamps and their spectral potential.

The advances in LED technology have opened up many new possibilities in lighting design, but at the same time have also changed the general requirements of the lighting environment. Today, the quality and "colours" of white light are discussed, as are the controllability and adjustability of applications. What was formerly a purely technical issue is increasingly developing to include human-centric lighting. The function of light is being related more directly and pragmatically to the needs of individual users.

The possibilities presented by LEDs have also increased the sophistication and conceptual scope of lighting design. New measurement variables have come into play alongside the familiar photometric parameters of illuminance, uniformity or light colour. Modern lighting designers must also pay attention to colour rendering, flicker and harmonic distortion and also provide information on the commercial rating of lighting systems. Further values such as amortization and return on investment (ROI) are also requested in addition to investment figures and operating costs.

Today's LED light sources claim to be suitable replacements for all previously available lamp technologies. Halogen, fluorescent or gas discharge lamps: luminaires fitted with LEDs can perform the functions of all these. In some modernization projects, only the light sources and lamps themselves are replaced and so-called "retrofits" actually generate the light. Naturally, LEDs can only unleash their full potential in lighting systems which are specially designed for this technology. There are good reasons for choosing either "conservative" or "innovative" approaches. It is the customers who decide – and who therefore require good advice on the technology in order to be able to choose the best solution.

This licht.de booklet on LEDs provides a comprehensive introduction to the technical background of this lighting technology – from special tips on particular applications in a wide variety of areas through to the key issues of the future, such as digitalization and human-centric lighting. In addition, standardization principles are discussed and the key indicators, values, costs and environmental aspects are presented. The booklet takes an integrated approach. Checklists, special advice and tips provide practical help for planners, installers and users, and make it easier to embark upon the future of lighting technology.

[02-04] Whether at work or in the home: the development of white LEDs has significantly extended the variety of light design possibilities. Flexible LED strips and controllable LED luminaires allow lighting designers and architects to meet almost all customer demands.

LED lighting throughout the day

Now that LED technology has established itself in almost all areas of lighting, developers are concentrating increasingly on the quality of the lighting and on new multifunctional possibilities. What this means for people and their everyday lives is described on the following pages, based on a very wide range of applications.

[05] Natural light varies between 3,000 and 12,000 kelvins during the course of the day.

[07] Older people require a significantly higher level of illumination in order to find their way effectively around rooms. In addition, circadian light can support the natural day/night rhythm.

Since the invention of the all-purpose lamp, no light source (and its properties) has had such revolutionary consequences as modern LED lighting solutions. LEDs are energy-efficient, small and, thanks to their technical properties, offer a variety of new functions. Lighting concepts based on LEDs can be found in almost all everyday situations and are now winning over even the most vocal critics with their useful characteristics.

For millions of years, human activity has been based around the light of the sun. This daily rhythm is essential for human health, especially from a physiological point of view, and yet people's habits are moving further and further away from it. Today, however, artificial light can simulate the dynamics of daylight and its many positive effects. Even if these findings are not new, the multifunctional LED control options are giving them new relevance and helping them to reach completely new customer groups. Today's LED luminaires and lighting systems permit infinitely variable changes in light colour and brightness and, if desired, allow the natural course of daylight to be dynamically simulated in order to exploit its positive properties in all areas of life.

05

LED light for hospitals and care facilities

Good lighting is a basic prerequisite for patient health. Superior lighting system functionality is of central importance. Patients and nursing home residents need individually adjustable lighting which is adapted to their needs, for example dimmable LED lights for reading in bed or for going to the toilet at night.

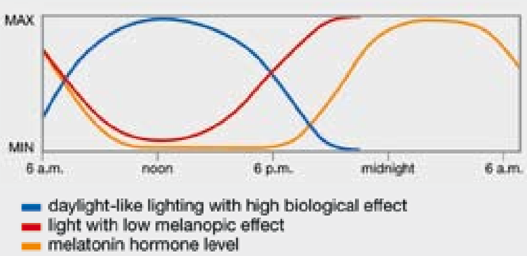
Medical personnel must also have the appropriate light for their visual tasks; here the main focus is on sufficient illuminance as well as good glare limitation and colour rendering.

LED luminaires come into their own especially in diagnostics and surgery. Very good colour rendering and adjustable light colours help medical staff to identify subtleties and details. Cold light colours are primarily used during diagnosis, while warm light colours are preferable in the nursing areas. Modern LED lighting can meet the different requirements by facilitating the control of both brightness and light colour.

Daylight changes its colour temperature throughout the day in a range from 3,000 to 12,000 kelvins. It thus shapes the daily rhythm of human beings and has an effect on our well-being, our ability to concentrate and our sleep rhythms. Put simply, the typical light colour at a particular time of day promotes or inhibits activity or relaxation. For example, warm light colours tend to induce relaxation in the evening, while cold blue light at noon supports activity. Based on this natural rhythm, interior spaces should be able to reproduce dynamic daylight – and thus promote good health – using modern LED technology. There is an extremely varied range of applications for healthcare lighting systems with colour temperature adaptation. With the right light colour, reception and waiting areas can be given a friendly ambience and workplaces can be designed to promote concentrated work. Rest and relaxation areas can be illuminated so that the selected light colour supports the user's needs there.

The prerequisites for the use of complex, controllable LED lighting solutions are meticulous and target-oriented lighting planning plus consistent implementation of the resulting lighting concept.

More information in licht.wissen booklet 07: Light as a Factor in Health.



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Circadian lighting

The circadian rhythm [06] refers to regular internal processes (such as the sleep-wake rhythm) over a period of roughly 24 hours. This rhythm is influenced by the spectral colour components and the intensity of the light, meaning that it is very important only to use lighting similar to daylight during the day (see blue curve). The body clock is controlled by the release of the hormone melatonin, which is usually only produced before and during the sleep phase. Light with a low melanopic effect (red curve) should be used at night, in the early morning and evening. If people are exposed to light with a significant blue colour proportion during this time, this disturbs the natural daily rhythm which could result in turn in sleep disorders.

07

LED light for educational institutions

The way in which knowledge is imparted at schools and universities is changing, and with it the lighting requirements. Electronic solutions and aids such as computers and projectors are increasingly being used in addition to blackboards, exercise books and books, meaning that flexibility is now paramount. Today, classrooms can be viewed – and illuminated – in principle like open-plan offices. This means, for instance, that indirect light must be available in order to ensure glare-free working in all parts of the room.

Flexible LED lighting control

More than ever, training and classrooms now make use of flexible seating to accommodate a wide variety of activities and needs. Group work, exams, creative phases and projector-based presentations each require different lighting scenarios. Modern LED lighting systems facilitate the selection of these scenarios and their adaptation via touch panels, multifunction switches or tablets. But there are also networked, intelligent controls that automatically detect the level of natural light currently available and the amount of light needed by users in the room at any given time. On a cloudy day in winter, for example, the light is dynamically adjusted. If the projector is switched on during the day, for instance, the lighting automatically dims and adapts to the new situation. If a particular room in the building is empty, however, the light automatically switches off to save energy. Yet despite all these practical automatic systems, it should always be possible to intervene manually and leave auto mode. Simple and intuitive setting options are called for here.

Based on our understanding of alterable light colours and their effect on human biological rhythms, colour-dynamic light control is not only desirable, but entirely conducive to the learning performance.

Optimized levels of light and shade also have a decisive influence on the working conditions in the room and are determined by the choice of luminaires. This is where the lighting designer comes in. The (in many cases) long-overdue modernization of older lighting systems through the use of economical LED luminaires and optional presence detectors quickly proves to be a worthwhile investment. All requirements and wishes with respect to energy-efficient, functional and flexible lighting can now be easily and comprehensively met using LED technology.

More information in licht.wissen booklet 02: Good Lighting for a Better Learning Environment

[08, 09] The selection of light colour and illuminance has a major impact on concentration levels.

Illuminance in the classroom:

[10] DIN EN 12464-1 stipulates that an illuminance level of 300 lux is required in the seating area of classrooms. However, this should only be regarded as a minimum value, as a level of 500 lux is recommended. This level is also prescribed for specialist classrooms and evening classes. The presentation areas and the area in front of the black/white board should have a uniform vertical illuminance of at least 500 lux; this should also be regarded as the minimum recommended value. This light should have a separate, individually switchable light source. The use of adjustable lighting systems is appropriate in order to meet the requirements for different classrooms and training rooms.

Further information available in the guide to DIN EN 12464-1 Lighting of workplaces.

LEDs for offices and administration

The use of innovative LED solutions increases office lighting quality while yielding a lasting reduction in lighting costs. LED lighting, used correctly, makes a major contribution to the quality of life: it helps people concentrate while working and when communicating with each other. The result is satisfied employees who then ultimately perform better.

Office and administration buildings, too, benefit from the many possibilities offered by LED technology. LEDs can be used for energy-efficient lighting in all areas – from reception desks to corridors, staircases and workstations. On the one hand, LEDs have significantly changed the appearance of classic office luminaires for the better. On the other hand, today's lighting concepts are increasingly adapting to people's needs. In the not too distant future, appropriate individual lighting which takes into account the lighting requirements at different times of the day will no doubt be available at every workplace.

The intricate and extremely powerful LED modules offer plenty of scope for innovative luminaire design. Room elements and furniture can easily be combined thanks to the superior integrability of LEDs. The luminaires then meld with the function of the room. It is also advantageous if there is an individually switchable light source at the workplace itself.

Illuminance levels in and around the workplace

[13] In terms of required illuminance levels, offices are subdivided into the actual workplaces (including work surfaces), the surrounding areas and a 0.5 m fringe zone up to the walls. According to DIN EN12464-1, the workplace must be illuminated with at least 500 lux and any partial areas requiring increased visual quality must be illuminated with 750 lux. The surrounding area must have at least 300 lux, while there are no restrictions for unused fringe zones. Additional vertical illuminances of 175 lux are required for shelving areas, for example.

Flexible luminaires or a correspondingly high general lighting level in the entire room are recommended for coping with the various uses of the different areas and the occasional shifting of workplaces.

It is technically very easy to control LED luminaires using switches, dimmers and smart controls. This leads to high user acceptance.

The multifunctional control options of modern lighting systems deserve special mention. These include lighting solutions that can be switched or dimmed automatically by presence detectors and brightness sensors, and that display swarm behaviour. Wireless systems enable simple communication between the system elements in the building. These can be configured and controlled via tablet or smartphone with an appropriate app or voice assistant. The next logical step is to evaluate this data in order to provide users with better lighting. Such data also helps facility managers to make more effective use of the rooms and reduce costs.

More information in licht.wissen booklet 04: Office Lighting: Motivating and Efficient.

[11, 12] Flexible and static lighting solutions for office and administrative buildings.

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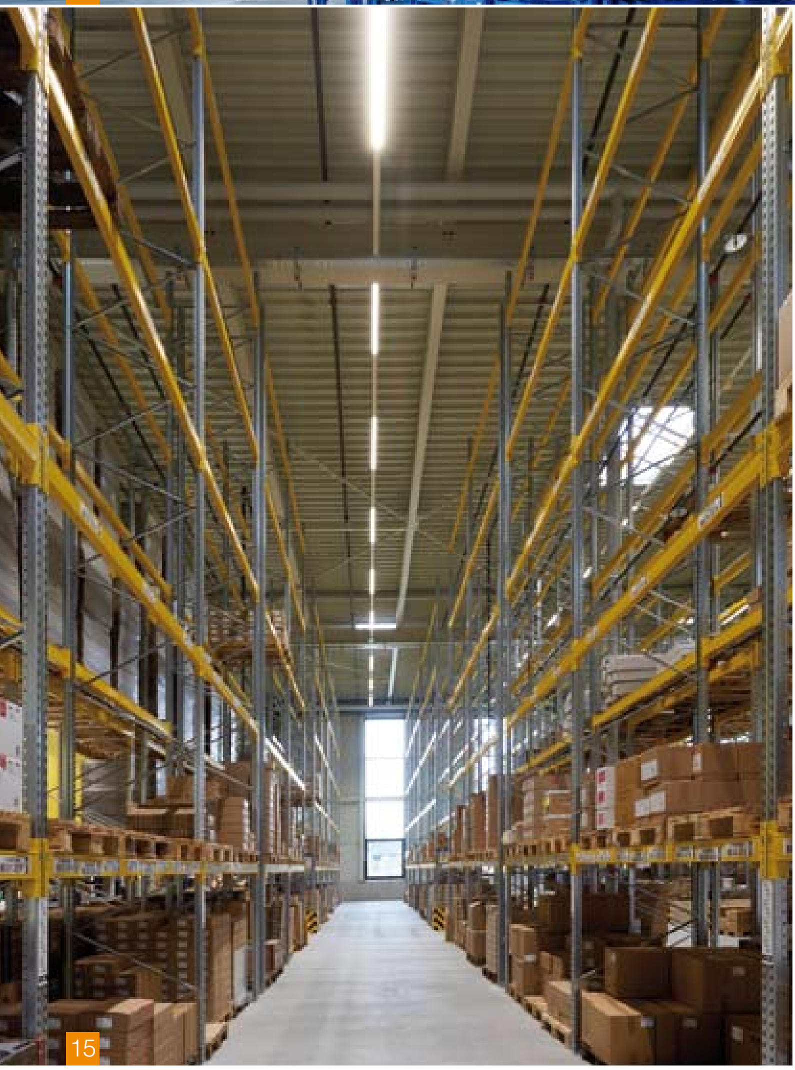

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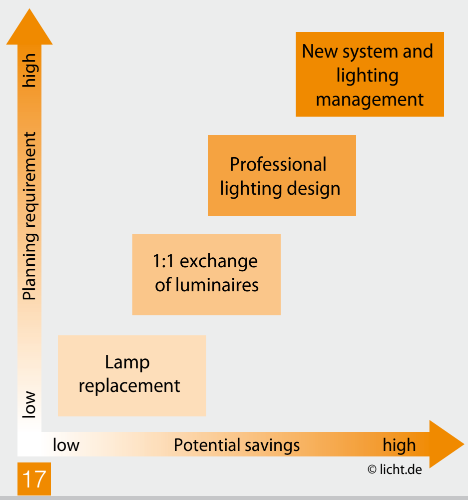
[14] Warehouse and production facilities must have suitable outdoor light quality to ensure safety and good vision.

[15] The passageways in a high-bay warehouse must be illuminated to allow safe access and to adequately illuminate the goods. Markings and signs in particular must be clearly legible.

[16] LED luminaires offer the perfect light for production areas due to their quality, flexible light distribution and simple control options. Concentration levels can be raised noticeably by choosing the right light colour.



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Modernization options

[17] Annual operating costs can be significantly reduced by investing in new and efficient lighting. Ongoing maintenance costs can be lowered at the same time. Even simple modernization measures can yield significant improvements. Customers and lighting designers should discuss the various modernization options on site. In general, there are four basic modernization stages. The comfort levels and possible energy savings increase at each stage. Options include:

- Lamp replacement
- 1:1 luminaire exchange
- System planning
- Use of lighting management systems

LEDs in trade and industry

According to the Federal Statistical Office, around 8.1 million people are currently employed in the manufacturing industry in Germany (March 2017). In contrast to offices, for example, the supply of daylight in industrial premises is usually limited by the building construction (high ceilings, lack of windows, etc.). This absence of daylight is also exacerbated by night working in cases where two and three shift systems are operated. The basic recommendation is to install greater vertical light components in places where physical work is performed.

In most cases, no lighting is required if the workplace is not occupied. Modern networked LED systems with presence-dependent control systems and light measurement sensors either adjust or switch off the lighting as required. This saves energy and in some cases reduces operating costs so significantly that, under certain financing arrangements, there is a positive “cash flow” from the time of conversion. A number of suppliers on the market have already used this as the basis for developing a business model; they take care of both installing and operating the system over a defined period without any investment costs arising for the customer.

Lighting levels decline faster in industrial workplaces than in offices due to ageing and dirt, for example. Employees often do not notice this gradual process.
This makes it all the more important to carry out regular inspections and, if necessary, maintenance work. With LEDs, the intervals can be extended significantly and also luminaire failures are considerably rarer than in conventional lighting. Very high energy efficiency levels and long service lives significantly reduce the running costs.

More information in licht.wissen booklet 05: Industry and Trade.

LEDs for modernization of commercial, industrial and administration buildings

Many companies are currently pressing ahead with the modernization of outdated lighting systems. The arguments in favour of LED lighting concepts – with their positive properties of energy efficiency, durability and superior lighting quality – are convincing. Various strategies exist for exploiting the benefits of the new technology. Sometimes it is sufficient to replace existing light sources with LED retrofits in order to reduce operating costs. Lighting points with outdated lighting technology are in use in some commercial enterprises and public areas; in some cases it is worth replacing these with LED lamps for a few years as a temporary solution, for example.

A second option is complete LED carriers which can be used, e.g., for converting existing light strips. In order to obtain maximum benefit from modern LED lighting technology a complete refit is, however, generally the best and most sustainable solution.

Ideally, the modernization should be carried out in three steps:
1) Assessment: Assess the lighting system with regard to lighting quality, energy saving potential and conformity to standards
2) Detailed analysis and lighting design: All parameters and findings are compared with each other and evaluated
3) Profitability calculation

Savings potential through modernization
Calculations of the energy consumption of old systems compared to modern LED lighting solutions are impressive. After only a few years, the investment will already have paid for itself, depending on how the systems are used. Furthermore, the long service life of LEDs extends maintenance intervals and thus offers further savings potential. Networking individual luminaires or integrating them into automated building technology systems also significantly increases convenience levels.

More information in licht.wissen booklet 09: Refurbishment in Trade, Commerce and Administration.

[18, 19] Modern LED shop lighting meets highly exacting colour rendering, illuminance and light accentuation demands.

[20] Focusable LED spotlights create accents and draw attention to key aspects.

Lighting of foodstuffs

LED technology can use its qualities and possibilities to optimum effect in retail applications. The reduced UV and heat radiation levels alone have a particularly positive effect on sensitive foodstuffs. But LED luminaires also offer advantages in terms of light colour. Luminaires with very high colour rendering values provide the ideal lighting for fruit and vegetables. Sausage and meat products are lit using optimized spectral ranges with higher red components while fish is illuminated using cool light. Warmer colours should be chosen for the cheese counter. Bread and baked goods can also be illuminated to great effect using this light. LEDs offer high colour saturation which makes them ideal for the illumination of food.

LEDs in shops

The low energy consumption and reduced maintenance costs of LED technology have convinced many retailers of the benefits to be obtained by updating their lighting. This is extremely important, as lighting accounts for around 25 per cent of total electricity consumption in the retail sector. Assuming that shop interiors are refreshed every 7 years on average (equivalent to approx. 28,000 operating hours), the main focus is not on the longest possible service life, but on achieving very high reliability in terms of failure and loss of luminous flux. This is ensured by the use of high-quality, maintenance-free LED luminaires.

Product presentation and branding

A flexible lighting solution including simple interchangeability and adjustment are the most important requirements for modern in-store lighting. Excellent illumination of the goods, the product displays and the sales areas creates a positive atmosphere which ultimately encourages customers to buy. Thanks to their small geometric dimensions, LED luminaire systems can be used that permit much greater flexibility in terms of their design and form. In addition, LEDs can be used to create beam characteristics which are much more precise and efficient. LED luminaires do not require additional UV or IR protection filters, as the light spectrum of LEDs only covers the visible range. As a result, the goods are not exposed to heat and hard radiation. The high colour rendering of LEDs meets modern store design requirements. The diverse lighting options of LED technology (e.g. RGB controls) make it possible to create targeted and effective lighting effects.

Interconnected lights in shopfitting

Modern LED luminaires with integrated sensors allow customer behaviour to be analysed using special software, thereby helping to support the procurement process. Intelligent networking allows additional product information to be displayed on smartphones or tablets or shown on multimedia displays. This gets around space and time restrictions, such as limited sales areas or store opening hours. Networked luminaires could already be regarded as a fourth dimension, the temporal factor of lighting.

More information in licht.wissen booklet 06: Shop lighting.

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LEDs in museums and exhibitions

A museum represents a themed experience in which a wide range of exhibits are presented using a sophisticated lighting system. The objects to be illuminated range from two-dimensional pictures or photographs through to three-dimensional sculptures. In addition to the illumination of the individual exhibits, the general basic lighting is also important as a result of the varying visitor numbers. These complex requirements can be met by a complex LED system.

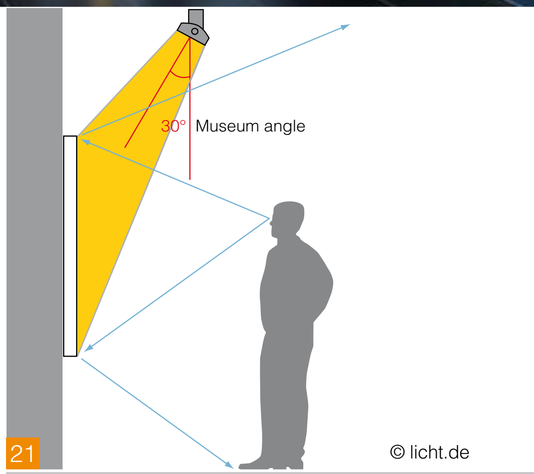
Appropriate lighting for sensitive exhibits

Since the exhibits often include valuable individual pieces, special care needs to be taken when selecting the appropriate lighting technology. In particular, excessive heat and UV radiation must be avoided, as some exhibits are particularly sensitive and the result could be irreversible damage. LED luminaires are perfect for such applications, as there is very little heat radiation in the light beam and the colour spectrum extends no higher than the near-UV range. Conventional lighting technologies are usually more problematic and can cause problems in cases where sensitive lighting is required. In addition, high colour rendering is absolutely essential to display the works of art as they were intended to be seen by the artist. Warm to neutral white light colours create a pleasant ambience and engender a sense of well-being in visitors.

Lighting as a work of art

In order to raise the appeal of the museum and exhibition environment, exhibitors are increasingly making use of multimedia lighting presentations. A stimulating interplay of light and colour between the walkways and the illuminated exhibits can create a new world of experience. Corridors and neutral surfaces are deliberately illuminated more diffusely in order to eliminate spatial boundaries and soften hard contours. This clearly accentuates and highlights the exhibits. Different beam angles, optionally adjustable colour temperatures and modular lighting systems provide the flexibility required to meet changing exhibition preferences. Networked lighting solutions also enable the interactive integration of light in exhibitions.

More information in licht.wissen booklet 18: LEDs in Museums and Exhibitions.



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Correct positioning of luminaires

[21] Paintings and sculptures are best illuminated with a 30° angle of incidence. This avoids the streaks of light and excessive shadows at the lower edge of the frame which would result from steeper angles. The possibility of visitors casting a shadow on the exhibit or seeing an image of themselves increases at angles of more than 30 degrees. Unwanted reflections and possible shadows can be avoided by illuminating the exhibit from two different directions. Incident light can be reflected on glass-framed pictures or photos, resulting in unpleasant glare. This is avoided by using appropriate lighting angles, shielded light-emitting surfaces and narrow light beams. It can be productive to involve the artist in the choice of illumination for sculptures in order to obtain the desired lighting effect.

LEDs in sport and leisure

Modern LED technology is ideal for the lighting of sports facilities – with positive effects for operators, athletes, spectators and local residents. Operators benefit from lower energy costs and longer service lives – combined with greater reliability and a significant reduction in maintenance costs. The shock resistance of LEDs also makes them exemplary ball-proof luminaires. Athletes and spectators benefit from the better lighting quality of the LED luminaires and are also less affected by dazzle. Even residents and the environment benefit, as the light can be focused very precisely on the playing field and not on the surrounding area.

The lighting quality, which is defined in EN 12193 and should be adapted to the specific local conditions, is decisive in the selection and planning of the lighting system. The values are based on the lighting classes of the standard.

Modern LEDs offer a multitude of options and a completely new dimension of flexibility, be it through local control using smartphones or tablets, or via a PC in the control room. Interconnected LED lighting systems grant full control over the lighting at all times. This allows those in charge to set the right lighting for the next match quickly and easily. In addition, the operator always maintains an overview of the electricity costs, the use and condition of the lighting system.

The spectators at the venue itself must be able to follow the events, but so, too, must viewers at home. To achieve this, it is necessary to create lighting which is also suitable for television. The demands are particularly exacting in the case of high-resolution television broadcasts (e.g. including super slow motion replays). Using conventional 50 Hz lighting systems this is not possible without flicker. Modern LED solutions also offer appropriate performance with regard to the required illuminance levels.

Protecting nature and the environment

The UV-free light of LED luminaires ensures that insects are less attracted to them than to conventional lighting. The use of asymmetrical reflectors with low light scatter levels further improves insect compatibility. The requirements of the Federal Immission Control Act must also be taken into account in conjunction with the LAI (Länder Committee for Immission Control) document regarding light pollution.

Further information and normative requirements for the individual sports can be found in licht.wissen issue 08: Sports and Leisure.

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LEDs for roads, paths and squares

Lighting in public areas ensures good visibility in road traffic and significantly raises the public's feeling of safety. Local communities can make considerable savings due to the superior cost efficiency (low energy consumption and long service life) of LED street lights. In addition, modern LED luminaires blend harmoniously into the cityscape with their attractive forms, and new design options are available for the lighting of streets and squares. Interconnected lighting solutions increase operating convenience and system availability.

In many German cities and communities, street lighting accounts for 30 to 50 per cent of municipal electricity consumption. In small communities, this figure can even exceed 50 per cent. Energy-efficient LED luminaires significantly reduce the lighting operating costs. Many local communities recognized this early on and pioneered the introduction of LED technology for general lighting. Public funding programmes are still being used to support this development. Conventional luminaires, by contrast, no longer feature in the planning of lighting systems.

LED street lights have a long service life. In the past, all light sources had to be replaced after two to four years. Today's LED modules and control gear are designed for replacement intervals of twelve to fifteen years. This considerably reduces maintenance work and costs.

The optional interconnection and use of sensors in the respective luminaires increase the benefits of LED outdoor lighting. This allows operating states and possible errors to be collected centrally, thus facilitating maintenance planning. In addition, the use of presence detectors enables demand-based control, which ultimately offers additional savings potential and further extends the service life. They can also be used to implement parking guidance systems and to obtain precise traffic measurements.

Outdoor LED luminaires also offer environmental advantages: light pollution into the night sky is reduced. Warm-white LED light sources emit an insect-friendly light spectrum.

More information in licht.wissen booklet 03: Roads, Paths and Squares.

[22, 23] Low energy costs, flexible control options and the high lighting quality of LEDs offer major advantages for sports facilities.

[24, 25] Interconnecting modern LED luminaires increases their flexibility and ease of maintenance.

LEDs for hotels and hospitality

A visit to a hotel or a restaurant should always be a special experience. The architecture and interior design, but above all the overall lighting planning are important factors here. Light can reinforce the corporate identity of the building or hotel chain in all areas. "Light to look at" – i.e. light objects such as large shade luminaires or light objects in the foyer (typically chandeliers) – always create inviting and welcoming lighting effects. Selectively used coloured light or corresponding control systems with colour and brightness gradients can also create light scenes that have a positive emotional impact on visitors.

Energy-efficient solutions

LED lighting offers numerous design possibilities, but its savings potential and the variable adjustment options of this lighting technology are also setting new standards. The 24-hour operation and frequent switching cycles common in the hotel and restaurant sector make LED solutions an attractive proposition. For example, corridors can be dimmed at night, or the lights only switched on when they are needed by means of presence detectors. A further advantage is that the full light output is immediately available when switched on and the service life is not affected by the switching frequency. LED luminaires emit significantly less heat than conventional lighting solutions, which considerably reduces the amount of air conditioning required in summer and thus leads to further savings.

Operators who are not currently planning a complete modernization programme can also save a lot of energy in the short term by means of LED retrofit solutions. In the long term, however, only complete refurbishment will exploit the full potential of modern LED luminaires.

More information in licht.wissen booklet 11: Good Lighting for Hotels and Restaurants

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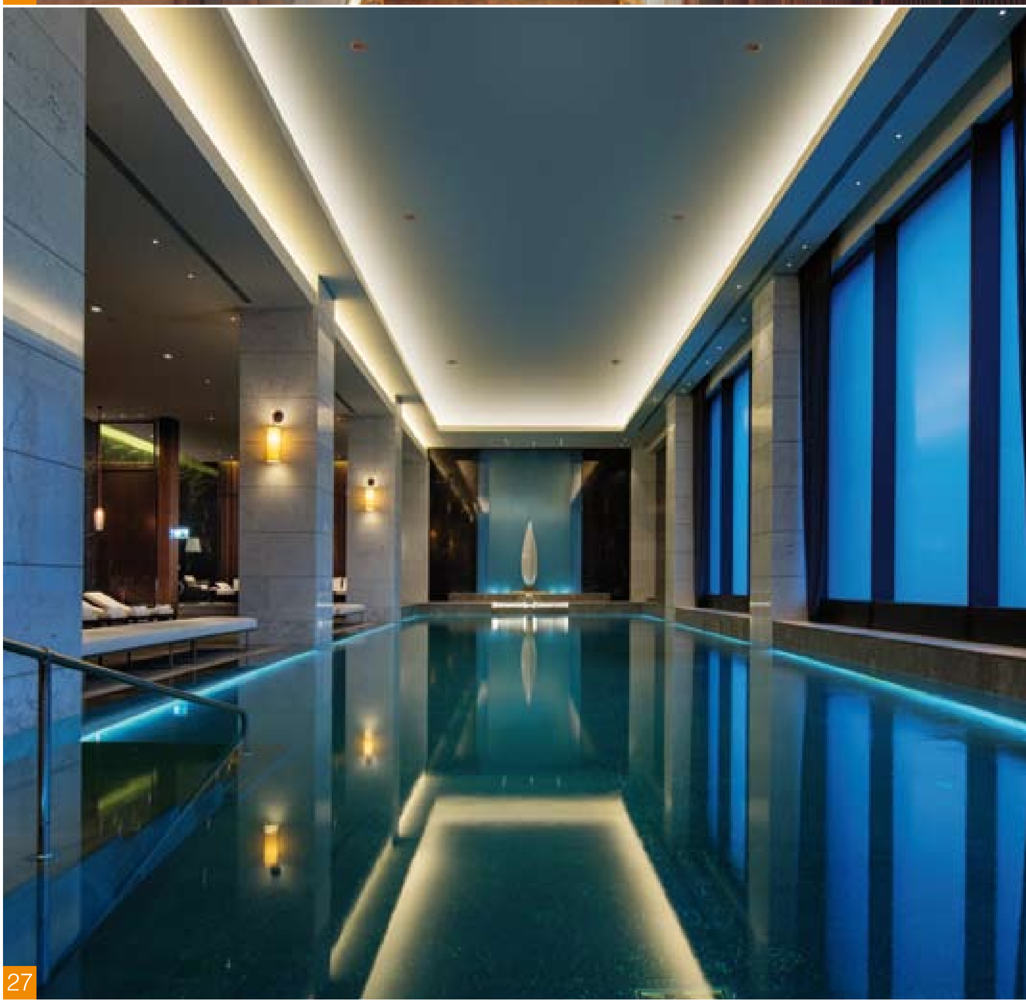

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LEDs for emergency and safety lighting

Safety and accident prevention are important aspects of lighting. In the event of a power failure, the emergency lighting powered by a backup supply source must switch on immediately. Escape signs mark the routes out of buildings; additional safety lighting helps to avoid panic, provides orientation and reduces the risk of accidents. Escape signs and safety luminaires are frequently in 24-hour operation. LED systems became established very early on due to their reliability and high energy efficiency. High-quality LED luminaires also have very long service lives. In practice, this means lower maintenance levels and significantly reduced operating costs.

Escape signs

In order to comply with the relevant standards, the concentrated luminance of the individual LEDs must be converted into a uniformly bright surface. Escape signs must also be clearly visible when the general lighting is on. The required average luminance is at least 200 cd/m^2 or 500 cd/m^2 for the white parts of the escape sign. It must be ensured that the luminous flux of the LEDs does not fall below these values throughout their service life. Escape sign luminaires should therefore have a built-in reserve which takes into account the decreasing luminous flux of the LEDs with age.

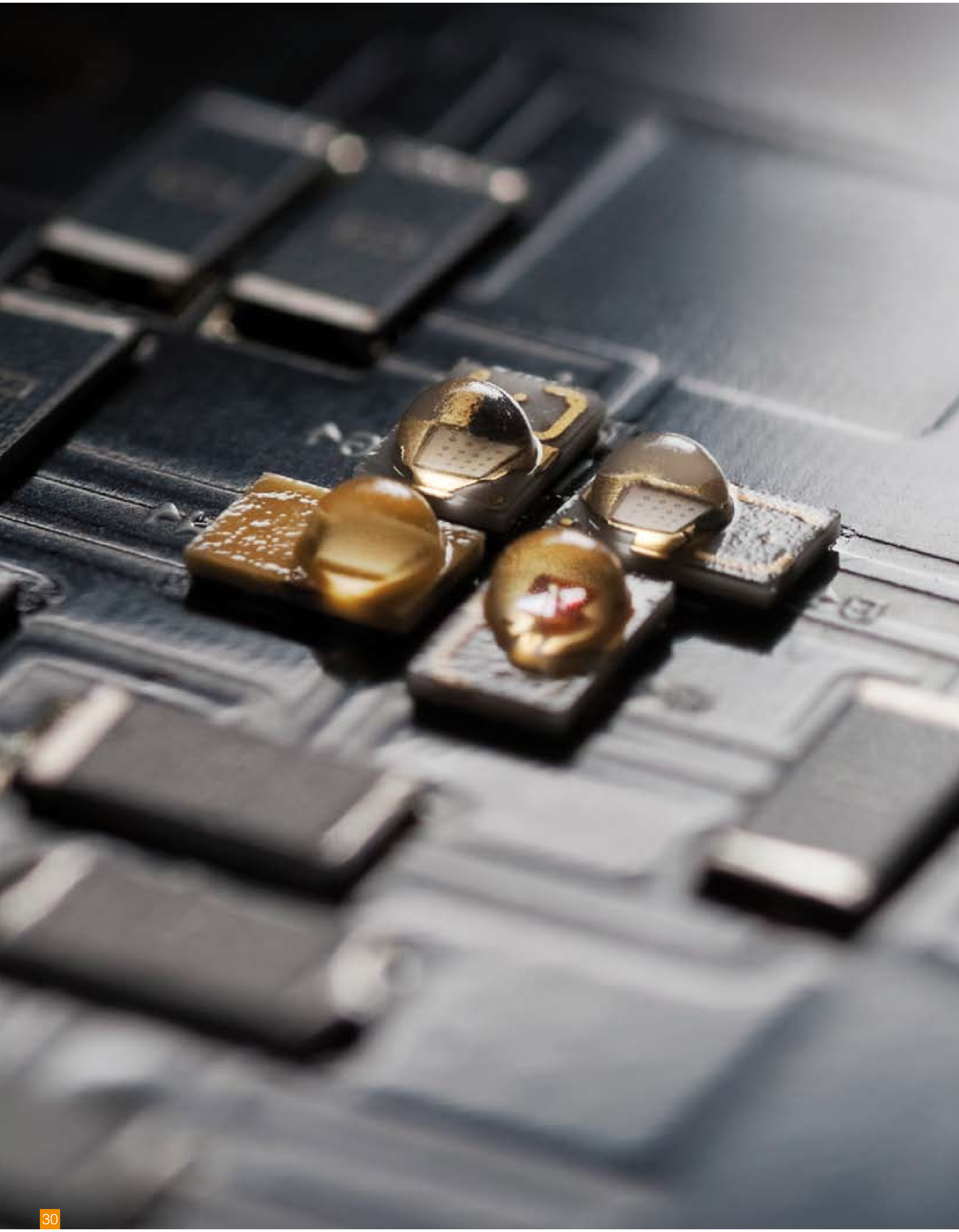
Safety luminaires

Due to the low installed load of LED safety luminaires, the backup power supply systems required for their operation can be kept small, thus saving costs.

More information in licht.wissen booklet 10: Emergency Lighting, Safety Lighting.

[26, 27] Light control systems open up attractive design possibilities.

[28, 29] LEDs are ideal for efficient and maintenance-free emergency lighting.



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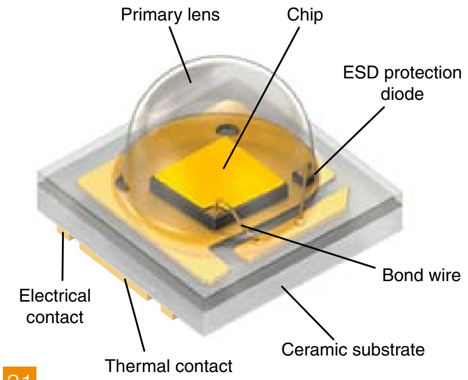
LEDs as a light source

Over the past 120 years, newly developed illuminants have repeatedly brought about major changes in the lighting market. However, no other light source since the invention of the incandescent lamp has revolutionized the lighting market as lastingly as LEDs.

The Englishman Henry Joseph Round discovered as early as 1907 that inorganic materials can be made to shine when current is passed through them. However, it was not until the 1970s that the first coloured LEDs were used in pocket calculators and watches, for example. White LED light only became possible with the first brightly radiating blue diode – developed in 1993 by the Japanese physicist Shuji Nakamura. This was the breakthrough and the basis for the first white LEDs that came onto the market a few years later. Nakamura received the Nobel Prize in Physics in 2014 for his invention.

Initially, the luminous diodes had a luminous efficacy of 1-20 lumens per watt of electrical power, but by 2013 this had already risen to around 80-120 lumens per watt. The further technical refinement of LEDs and the increasing demand for them brought down the initially high price level considerably. LED lamps and luminaires are now replacing all other established lighting technologies.

The basic principle of LEDs



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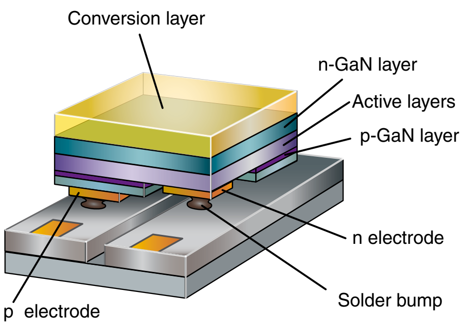
The light-producing chip in an LED (Light Emitting Diode) consists of a number of semiconductor layers (epitaxy layers) and connection elements. In the active layer, light of one wavelength (blue light in white LEDs) is generated when direct current is passed through the diode. Electrons and holes recombine in the semiconductor. Electrical energy is converted directly into light (electromagnetic energy) through electroluminescence. However, 50 to 70 per cent of the energy is still emitted as heat. This must be removed effectively if the luminaire is to have a long service life.

LED chip architecture



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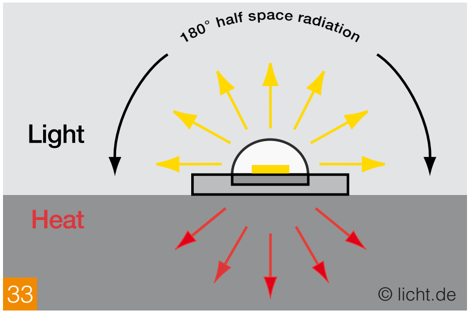
While conventional incandescent lamps emit a continuous light spectrum, chips emit one very specific colour. This is essentially dependent on the semiconductor material used. The chip is usually mounted in a casing. This so-called package also routes the electrical contacts to the exterior and contains the conversion layer (phosphor) for generating white light. The package also performs other functions, e.g. by containing protective circuits, optical lenses or heat dissipation elements. The chip(s) and package unit is usually referred to as an LED.

LED characteristics

The key lighting characteristics of LEDs are their service life, efficiency, light colour, colour rendering and luminous flux. Ongoing development means that most of these parameters remain dynamic characteristics. LED efficiency values have steadily increased over the last few years. LEDs delivering over 200 lm/W are already in use. There is currently no end in sight for these technological developments, but figures of over 250 lm/W are now possible in high-quality luminaires (see also Figure 35 on page 24). Such values cannot be achieved with conventional light sources.



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A contributory factor to the high luminaire efficiency is that the light emission of the LEDs is emitted over a half-space of 180°. In LED modules, for example, the light is emitted in one direction, while the heat generated in the LED is dissipated in the other direction.

[30] Close-up of circuit board with LEDs. The current-carrying tracks are clearly visible.

Quality features of LED light

After years of focusing on LED efficiency, more and more attention is now being paid to light quality. Aspects such as light colour, colour rendering, flicker, photobiological safety and the behaviour of LEDs during dimming are central here.

Light is essential for people – so is good light quality. But what determines good light quality? Above all, the lighting level must be right, because visual tasks can only be performed if there is sufficient light. Too little light strains the eyes and is tiring, too much light can be irritating and dazzling. Good visual perception in a room is also determined by the brightness distribution, the light direction and by modelling. These are positive influences on three-dimensional vision.

Quality features: Light colour

The light colour of LED light sources affects people's psyche and emotions. Warm white light is often used in the home environment, while neutral or cool white light is often deployed in the work place. Almost all LED products are now available in warm white (< 3,300K), neutral white (3,300K to 5,300K) and cold white (> 5,300K). The emission spectrum determines the colour temperature, but also has an effect on the circadian rhythm of humans and is an important criterion in the planning of biologically effective lighting. See also Human Centric Lighting, pages 38-39.

Quality features: Colour rendering

Good colour rendering by LED products is achieved using special conversion materials. A colour rendering index R_a of 80, 90 or more is currently possible. The colour rendering index R_a of a light source describes how similar a body colour is represented in comparison to daylight or the light of an incandescent lamp (R_a =100). Light spectra with good red rendering generally enjoy high acceptance levels by users. The authentic

Intermittent flicker, flicker, stroboscopic effects

Intermittent flicker is used to describe light that comes on and goes off at short, irregular intervals. This effect is familiar, for example, when fluorescent lamps are switched on.

Regular fluctuations in brightness are referred to as **flicker**. These fluctuations are consciously perceived by humans at low frequencies (in extreme cases up to approx. 80 Hz) and are regarded as very unpleasant. However, they can also have negative effects on our health, e.g. at higher frequencies of 80-400 Hz, and can cause headaches.

Stroboscopic effects can change the perception of movement in rotating or reciprocating machine parts, possibly rendering them no longer visible. For example, a rapidly rotating machine can increase the risk of injury because the eye is led to believe that the machine is at a standstill.

[34] Irritating flicker from light sources is determined by modulation (curve amplitude) and frequency (Hz). The graph shows that optimum results can only be achieved at high frequencies and a low modulation depth.

and brilliant colours of an illuminated product can be further enhanced by the selection of suitable LEDs. Special LED spectra are now used especially in retail stores; these provide excellent light for displaying the respective products, especially food and fashion. This can significantly increase the perceived value of the illuminated goods. The trend in the development of new general lighting technologies is increasingly towards continuous spectra with maximum colour rendering.

Efficiency versus light quality

The efficiency of the luminous flux of LEDs per electrical input is not a fixed value, but is constantly improving as a result of technical progress. Warm-white LEDs and LEDs with high colour rendering are becoming increasingly efficient and their values are scarcely lower than those of cold white LEDs or LEDs with low colour rendering.

For further information on light quality and the quality characteristics of light, see licht.de issue 01, Lighting with Artificial Light.

Flicker of light sources

Flicker is rapidly changing brightness levels; it can be perceived as highly irritating by observers. But even subconsciously perceived flicker can cause symptoms and impact negatively on people's sense of well-being. This depends on the frequency and the modulation and can vary greatly from case to case. In a recommendation issued by IEEE 1789, flicker is divided into different basic categories. The recommendation describes the likelihood of such effects on humans.

The interaction of frequency and modulation (amplitude of the curve) is decisive here, as shown in Figure 34. The higher the frequency (in Hertz) and the lower the degree of modulation, the better and more flicker-free the product.

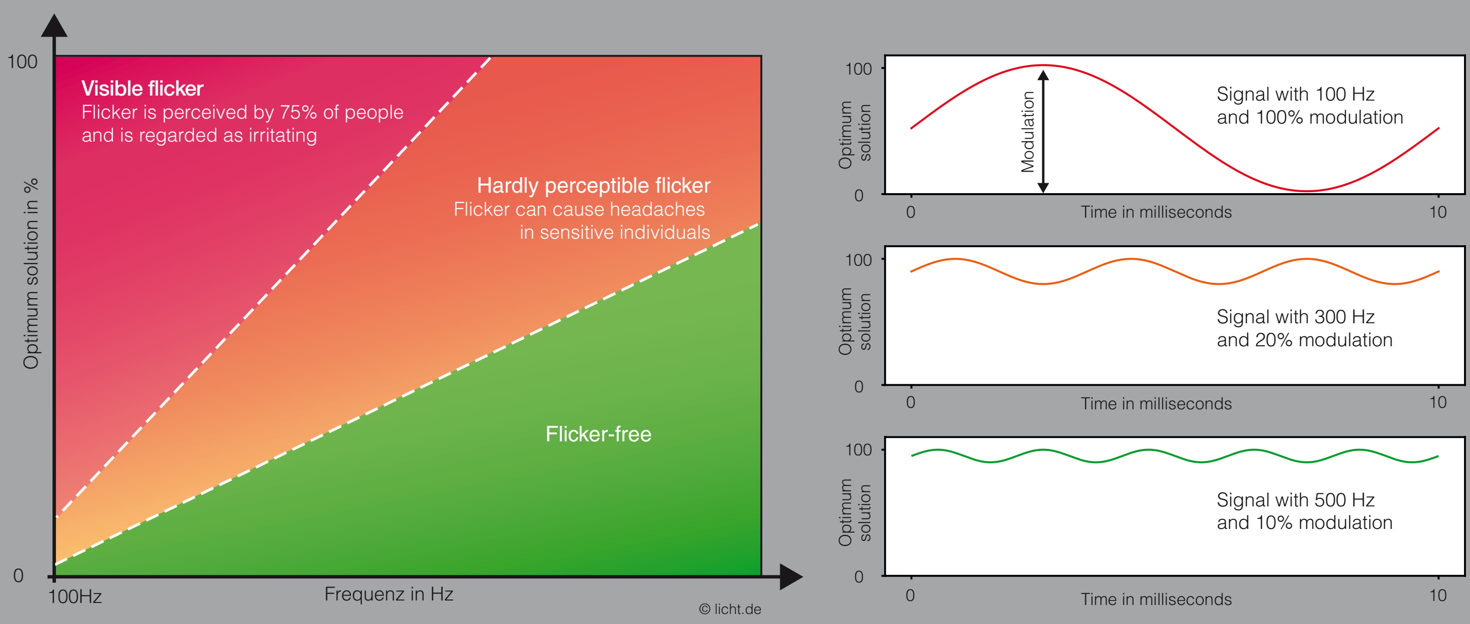
The example of **the red sine curve** in Figure 34 shows a strong curve deflection with a modulation depth of 100% at a relatively low frequency of 100Hz. Here, flicker is consciously perceived and is viewed as irritating.

The orange curve shows a range in which the modulation is significantly lower at 20%, but in which there is still a frequency of 300Hz. Even if most users only perceive a slight flicker, or no flicker at all, sensitive individuals may suffer negative effects such as headaches.

The green curve shows a particularly low amplitude of only 10% modulation at a high frequency of 500 Hz. This is an example of a very good solution which is almost flicker-free

Research into the effect of LED light source flicker on the human organism is still in its infancy. Recommendation: in order to ensure safe application, flicker-free luminaire systems should be used (see green area in the chart). If required, the relevant information should be requested directly from the manufacturer.

Light source flicker



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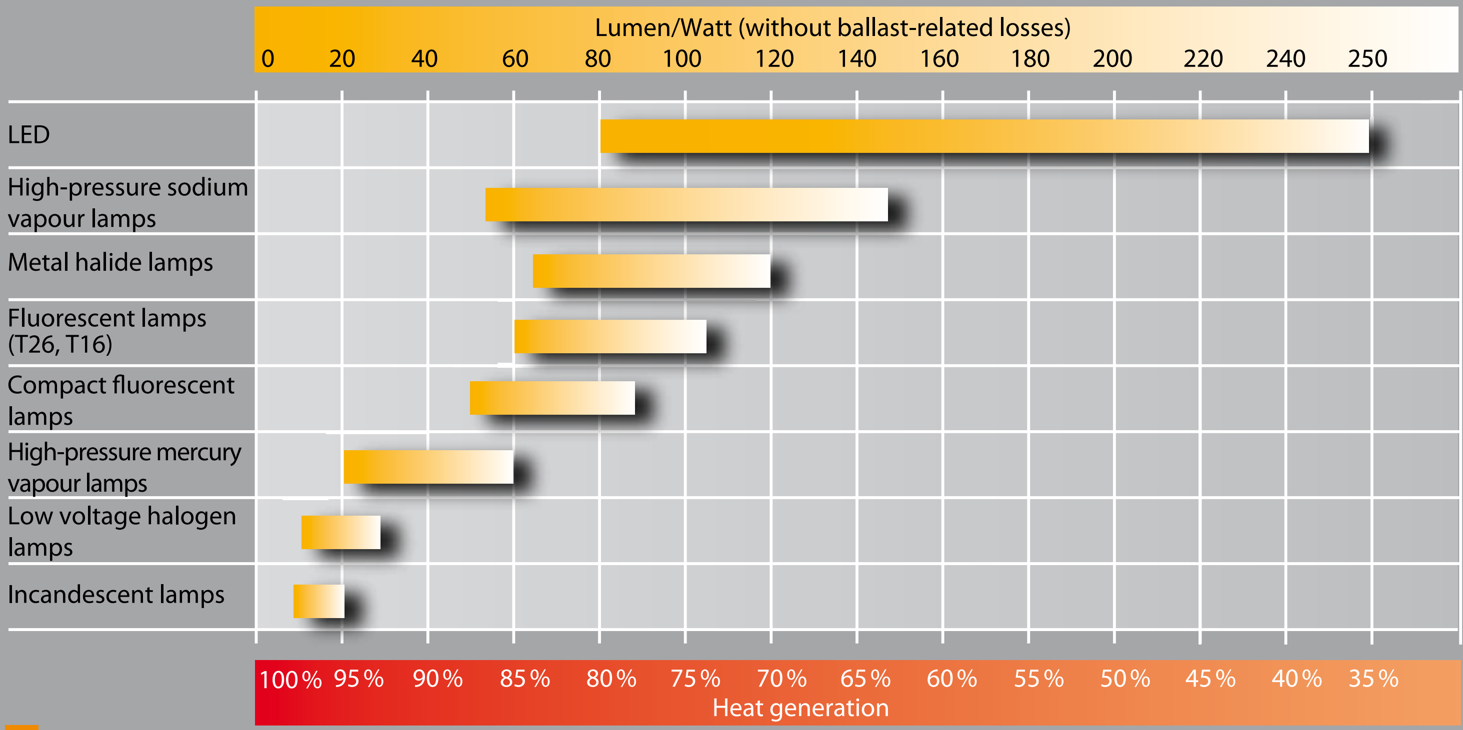
Efficiency and heat generation of light sources



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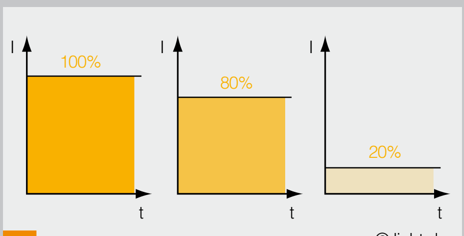
Dimming of LEDs

It is now technically possible to dim LEDs. It should be noted, however, that the light colour does not change during dimming. Yet, especially in the home environment, users expect the light colour to become warmer when dimmed, as was previously the case with incandescent lamps. To make this possible, both cold-white and warm-white LEDs are installed in the luminaire, thereby enabling "dim to warm" even in LEDs.

Current dimming:

Lowering the amplitude of the forward current leads to a reduction of the luminous flux (current dimming, Figure 36). Once a desired light or current level has been set, it then remains constant. This type of dimming is flicker-free, but the minimum adjustable dimming level is higher than with PWM dimming.



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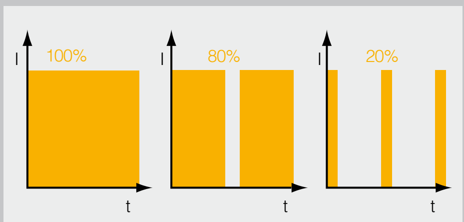
PWM dimming

The reduction of the mean value of the forward current – so-called pulse width modulation (PWM, Figure 37) – also causes LED light dimming. The current flow through the LED is periodically interrupted at a certain PWM frequency. The longer the pauses between the current phases, the lower the effective or average current through the LED and thus its perceived brightness.



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Compared to current dimming, PWM dimming can cause subconsciously or directly visible flicker in LED light. For this reason, the system (consisting of luminaire and control unit) must be assessed in its dimmed state and evaluated in accordance with Figure 34 (p.23).

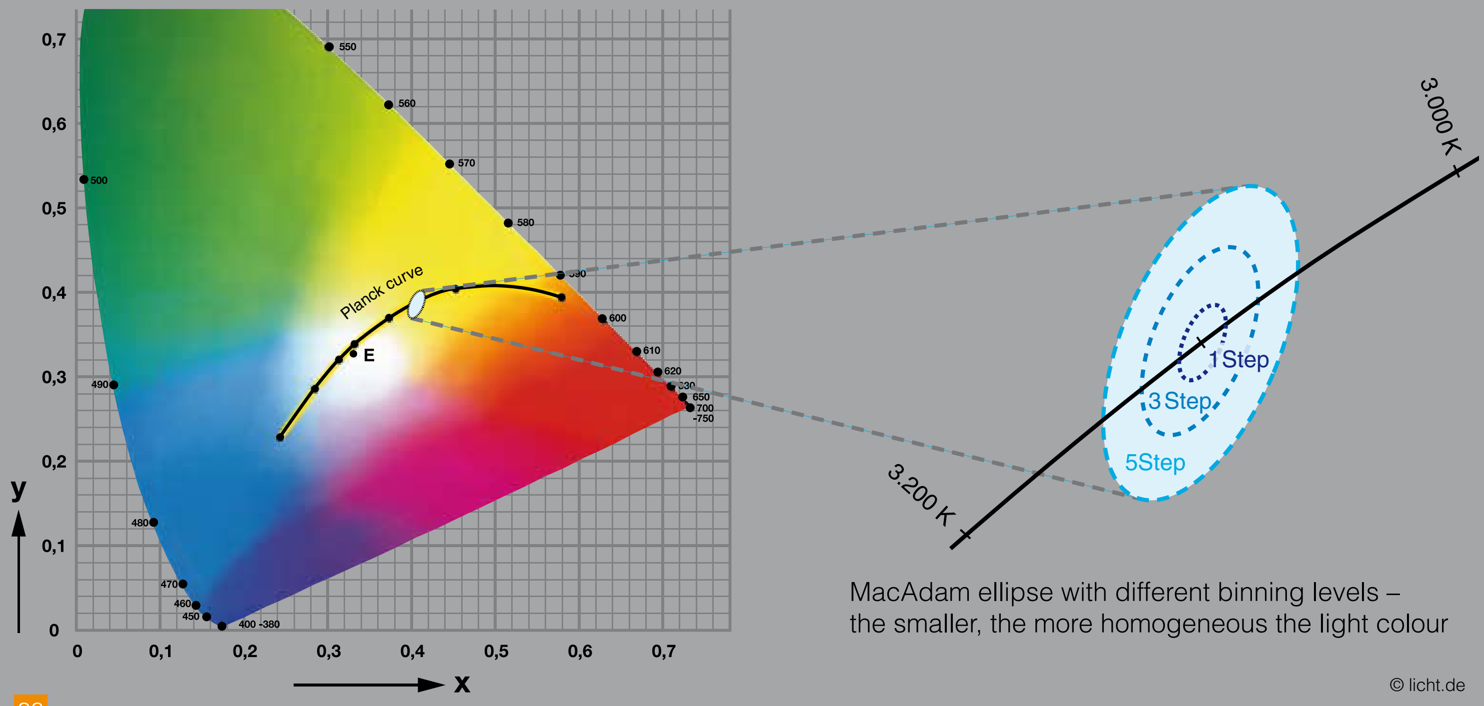
Service life and degradation

LEDs have an extremely long service life. Incandescent lamps fail after approximately 1,000 hours and fluorescent lamps after approximately 18,000 hours (EB), while high-performance LEDs have a service life of 50,000 hours or more. The EnEV puts luminaire service life in offices, for example, at approx. 2,000 hours per year, corresponding to 25 years of use. Other applications, such as street lighting and 24-hour lighting, require a special maintenance plan which includes, e.g. the replacement of parts such as modules and drivers. The industry offers products for each particular application.

The service life and efficiency of LEDs depend to a great extent on the operating and ambient temperature. The colder the environment, the greater the efficiency of LEDs. The luminous flux and service life can be significantly reduced by high ambient temperatures. Efficient heat dissipation is therefore particularly important in the development of high-performance LED systems.

Unlike conventional lamps, LEDs hardly ever fail spontaneously. However, their luminous flux decreases over time. This property is called degradation and results in the LED system having to be serviced at predetermined intervals. These times are usually selected so that maintenance is carried out when the luminous flux emitted by the LED has

Standard chromaticity diagram with Planck curve and MacAdam ellipse



MacAdam ellipse with different binning levels – the smaller, the more homogeneous the light colour

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fallen to 70 (or 80) per cent of the original figure. Under no circumstances should the maintained value of the system fall below that given in the standard.

Binning

All LEDs exhibit variance in the light colour, luminous flux and forward voltage parameters. Users quickly recognize any differences in the light colours. The manufacturers are responsible for ensuring that only LEDs are installed in the luminaires which create the most homogeneous colour impression. All LEDs in a batch must be sorted to ensure uniform light colour and constant lighting quality at the same brightness level. They are divided into so-called “bins”.

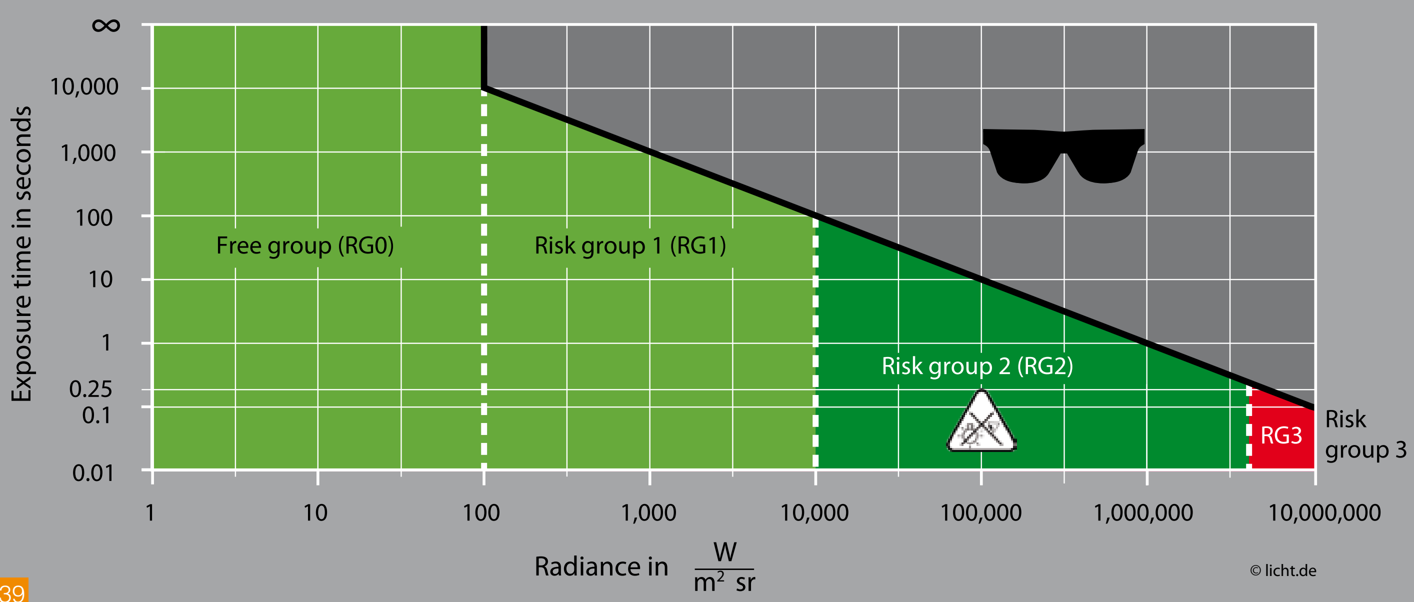
This binning process is particularly important for white LEDs. The smallest colour difference perceptible to humans is defined using one-step MacAdam ellipses. It is not possible to distinguish between colour nuances of products within these ellipses. The tolerance ranges required for binning are determined by the application of the luminaire. The more precise the LED binning, the higher the costs.

Further information is available in the guide to DIN EN 12464-1.

[35] Comparison of efficiency and heat generation in different light sources.

[38] The colour nuances of products within a one-step MacAdam ellipse are indistinguishable to the human eye.

Risk classifications of light sources



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Labelling of blue light hazard of lamps:

Light source	Action, labelling
LED modules	The light source should be classified, and measured if necessary. Labelling is not necessary if an RG 0 or RG 1 rating is given. Above RG 1, the distance is given at which the threshold illuminance Ethr returns the product to RG 1.
LED lamps, retrofits	These lamps may only be specified as RG 0 or RG 1 products as, like the lamps they are replacing, they must not present a risk. No labelling is required.
LED lamps, non-retrofits	The light source should be classified, and measured if necessary. Labelling is not necessary if an RG 0 or RG 1 rating is given. Above RG 1, the distance is given at which the threshold illuminance Ethr returns the product to RG 1.
Incandescent lamps, tungsten halogen lamps, all fluorescent lamps (compact, with and without self-ballast, linear), induction lamps	No labelling is required for these light sources as no hazard can arise.
Special tungsten halogen lamps (for projection, photography, stage lighting and special applications)	These light sources are labelled with pictogram 1. 
Low and high intensity sodium-vapour discharge lamps	No labelling is required for these light sources as no hazard can arise.
Mercury vapour high intensity (including mixed light) and halogen metal vapour discharge lamps (all with coated or matt shroud)	No labelling is required for these light sources as no hazard can arise.
Mercury vapour high-intensity and halogen metal vapour lamps with clear shroud	These light sources are labelled with pictogram 1. 

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Photobiological safety

Consumers have nothing to fear: LED luminaires are basically no more hazardous than any other light sources when used properly. European and national standards oblige manufacturers to uphold safety levels and to draw attention to any relevant dangers.

A situation familiar to everyone: looking directly at the sun makes us close our eyes involuntarily, or turn away. As children we learn that this is unhealthy and can damage our eyes. Looking directly at artificial light sources is just as unpleasant. Here the hazards are evaluated very differently and user protection is regulated by standards.

The General Product Safety Directive 2001/95/EC and the Low Voltage Directive 2014/35/EU (LVD) require that humans must not be harmed by radiation. This also applies, of course, to the light from LED lamps and luminaires. In addition, EU Directive 2006/25/EC (Protection against artificial optical radiation) defines "minimum requirements for the protection of workers from risks to health and safety in the event of exposure to artificial optical radiation". The risk classes of light sources are described in standard EN 62471.

When looking directly into the light source, there is a risk that the blue light radiation and the luminance, which is highly concentrated in a very small area in some cases, will damage the eyes. To prevent this, the photobiological safety of light sources must be tested. If necessary, measures must be taken such as labelling risk group 2 products and providing corresponding information in the installation instructions. It is the responsibility of the operator/user to ensure that the safety instructions are observed.

Blue light hazard

Blue light hazard is the potential risk of photochemical damage to the retina caused by radiation, especially in the 400 nm to 500 nm wavelength range. Basically, the colder the light, the higher the blue component in the radiation which can damage the retina over longer exposure times. When assessing the photobiological hazard arising from optical radiation, a distinction is made between the different wavelength ranges (UV, visible and IR radiation). The main aspect here is the depth of tissue penetration. The skin and eyes are affected in particular, as optical radiation does not penetrate deep into tissue.

UV and IR radiation are absorbed by the outer layers of tissue. The level of hazard and the stated maximum limits depend on the illuminance generated by a light source or the luminaire, and not on its physical dimensions.

A random, brief glance into a light source does not pose a threat. A natural protective reflex takes place: you close your eyes involuntarily (eyelid closure reflex) and avert your gaze. This reflex prevents the "blue light dose" from being reached which could result in possible damage.

Risk group (RG) hazard types

Measurement methods and radiance or irradiance limit values exist for all types of hazard. Lamps can be divided into risk groups (RGs) from level 0 to 3 based on these.

RG0 – No danger, no risk of eye damage, even when looking permanently in the direction of the light source (unlimited exposure time).

RG1 – Low risk. The eyes are not damaged, even when looking straight at the light source for a limited period of time (limited exposure).

RG2 – Medium risk. Damage to the eyes is avoided through the natural gaze aversion reaction. This presupposes that looking at the light source is perceived as sufficiently unpleasant. The radiance or irradiance limit value is set so that the eyes are not damaged by the radiation before the gaze is turned away from the light source (short exposure period). Light sources in risk group 2 must be marked as such (symbol 1) and carry a warning:

The minimum safe distance between luminaire and observer must be specified in the installation instructions.

RG3 – High risk. Even a brief glance into the light source can cause damage to the eyes and is therefore not permitted. There are no known risk group 3 lamps in general lighting. Moreover, RG3 products would not be permitted under the luminaire safety standard.

Further information can be found in the ZVEI brochure: Blue light hazard

[39] Risk classification of light sources RG0 - RG3.

[40] The table shows which light sources must carry a blue light hazard label.

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LED light sources

LED light sources are available in a wide variety of designs – from ready-to-use retrofit solutions to flexible LED strips and LED modules that meet even the most exacting demands. The LED portfolio includes perfect solutions for even the most challenging of special designs.

[41] Overview of common LED retrofit lamps, LED strips, LED modules and LED packages. A suitable LED solution now exists for every application.

Conversion

If a luminaire is modified to permit it to accept e.g. a tubular LED lamp, this is referred to as a conversion (or refit). This requires technical changes to the luminaire design. As a rule, the starter and the control gear must be replaced and the internal wiring exchanged or modified. The lighting properties of the luminaire always change, too, as the LED replacement has different radiation characteristics e.g. to a fluorescent lamp. The following points should be noted:

- Luminaires should only be converted by an authorized specialist company.
- The conversion voids the approval of the luminaire and, where applicable, the manufacturer's warranty, too.
- The conversion creates a new product which requires a new conformity assessment. This is the responsibility of the party modifying or placing the luminaire on the market, and who thus becomes the luminaire manufacturer.
- The conversion company carries responsibility for product liability and warranty.
- The converted luminaire must be given a new type plate.
- Lighting properties should be checked and, if necessary, adjusted to the legally prescribed values.

LED retrofit lamps

The quickest and easiest introduction to LED technology is to fit an LED retrofit lamp into a luminaire. The original luminaire (including socket) is retained, but is updated using state-of-the-art technology. Because the retrofit lamp has the same design, no structural changes need to be made to the luminaire. LED retrofit lamps are available in many versions, and are characterized by their high energy efficiency and good colour rendering. Depending on the system, they can also be dimmed, colour-controlled or integrated into a network using smart technology. NB: Electrical and photometric compatibility must be ensured when LED retrofit lamps are used in luminaires. Three main types are available on the market:

[1] Substitutes for tubular fluorescent lamps (T8, T5)

Tubular LED lamps require significantly less energy than conventional fluorescent lamps, exhibit no intermittent flicker when switched on and light up immediately with full luminosity. Note: See grey box on the left for information on conversion.

[2-3] Substitute for radiating light sources, single or double-ended

LED lamps can replace conventional incandescent and halogen lamps in the classic "bulb shape" and with E14 or E27 screw bases. Lamps with different plug-in bases (single or double-ended) can also be replaced with little effort.

[4-5] Substitute for reflector lamps

Conventional reflector lamps can easily be replaced by LED retrofit lamps. Here the market offers a large selection, with different light colours and beam angles.

[6-7] Flexible LED strips

Flexible LED strips are particularly suitable for decorative lighting. However, ever higher luminous fluxes are also rendering them attractive propositions for room lighting, for example in coves. In this case, it is imperative to ensure good heat dissipation.

[8-11] LED modules

LED modules are light sources that generate light using PCBs fitted with individual LEDs. Depending on the configuration, the modules can also be equipped with light guiding optics and a heat sink. Technical safety, reliability and performance requirements are described in Regulation 1194/2012/EU and the safety and performance standards DIN EN 62031 and DIN EN 62717. As a rule, ballast units are required to operate an LED module.

Starting point: The LED

The above LED light sources make use of the following LED components:

[12] Low- and midpower-LEDs with electrical outputs of 0.1 to 0.5 W are used. They consist of a simple plastic housing which includes a lead frame for heat dissipation and power supply, and a chip.

[13] High-power LEDs with an electrical output of 1-5W are often used in spotlights and street lighting. Precise light control is achieved by means of special plastic optics.

[14] Multi-chip-LEDs are constructed with highly integrated chips behind a larger conversion surface, e.g. CoB (chip-on-board). Application: e.g. downlights, hall and table luminaires.

The LED luminaire, a technological lighting system

LED luminaires are complex systems comprising lighting technology and electronics. LED luminaires typically consist of a housing, an integrated ballast, an optical system for light distribution and one or more LED modules for generating light.

It is crucial to use high-quality components to obtain a good LED luminaire. These include LEDs as light sources, usually in the form of LED modules. In an efficient LED solution, the LED modules and luminaire components must be optimally matched; they always form a complete system.
The system consists of the following components:

a) Control gear
The control gear is of great importance for determining the reliability of a luminaire. When luminaires fail, the reason is rarely the LED; very often the cause is defective control gear. It is important to use high-quality, tested and certified brand-name devices. However, the luminaire must also be designed to ensure that the control gear has enough space and does not overheat.

b) Housing with heat sink
Quality luminaires are characterized by the fact that the mechanical, optical and thermal design aspects are fully coordinated. Small installation spaces and high room temperatures still represent the greatest challenges for LED luminaires. Good thermal management is absolutely essential here. Always work together with experienced and competent partners to ensure reliable products.

c) LED modules
LED modules basically consist of a number of individual LEDs which are mounted on a printed circuit board by soldering. This ensures that the LEDs can be electrically connected and controlled, and that the heat is dissipated. The flat modules allow flexible and efficient use of LED technology, but there is currently no standardization of these components.

d) Optical system / Cover
In addition, secondary optics are used for targeted light distribution. Good optical systems, covers or diffusing lenses let as much light pass through as possible and allow it to be diffused or directed as desired.

Product quality
The quality of the LEDs and ballasts is of central importance in ensuring a long-lasting system. The quality and efficiency of LEDs are improving all the time. Luminaire values of over 150 lumens per watt are already realistic in some applications; this value will continue to rise in the coming years.

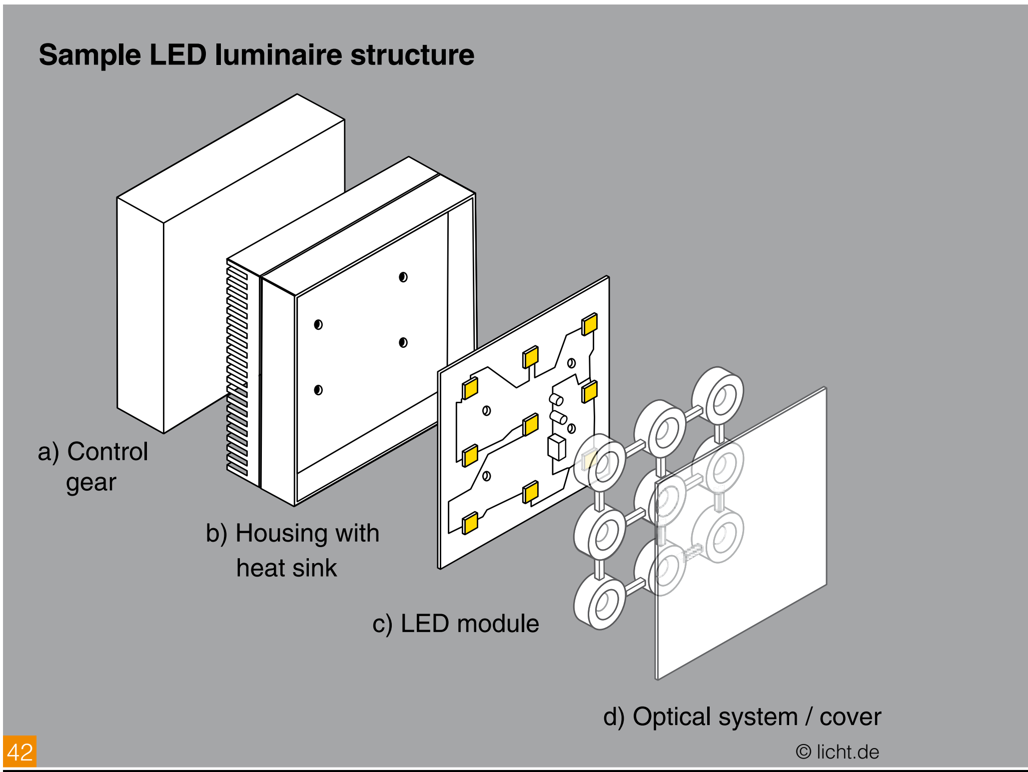
Furthermore, the manufacturer should have a high level of LED and lighting technology expertise. This plays a decisive role in the lighting design and optimum implementation of the customer's requirements. High product quality must be insisted upon right from the point when the decision of which luminaires are to be used is made. There is an important reason for this: if the luminaires no longer function properly, they must be replaced or repaired. Luminaires should be repaired professionally using original parts.

Long service life and replacement of LEDs
Thanks to the compact dimensions of LED technology, lamps and luminaires can merge to form an inseparable unit. This is precisely what must happen if good efficiency values are to be achieved. Given the very long service life of LEDs of 50,000+ hours, this is significantly less critical than many users fear. If there is a failure, the LED module is not replaced by the end customer, but by the manufacturer or a specialist – similar to changing the battery of a mobile phone. This is the only way to ensure that the thermal path is restored after repair and that the LEDs are not damaged during installation.

Examples of long service lives: in offices with usage rates of approx. 2,000 hours per year and a service life of 50,000 hours, one luminaire will last 25 years. It is therefore unlikely that an LED module will need to be changed. In many cases, the office will have been modernized and newer luminaires installed by then. Possible exceptions are street lights designed for very long service lives but also extremely high stress levels, and luminaires used in 24-hour operation. The possibility of maintenance-friendly module replacement should be taken into account right from the product selection stage.

There are exacting requirements for each component as integral parts of the overall lighting unit. The development of luminaires requires a high degree of technical design and production know-how as well as the use of high-quality materials and components.

Further information can be found in the ZVEI guide on "Reliable planning with LED lighting", 2nd edition.



[42] Sample LED luminaire structure. The heat generated on the LED board must be dissipated via a dedicated heat sink in the housing in order to maintain light quality and durability. The optics provide light control and allow the beam to be angled suitably.

[43] Lenses and diffusing lenses help to direct the light as required for the particular application.

Quality features: Product

LEDs have become established in all areas of lighting in recent years. The quality and service life of an LED depend on the optimum interplay of a wide variety of factors which will ideally enable it to operate for well over 50,000 hours.

[44] LED products which are used outdoors require a high degree of IP protection.

[45] Many different factors influence the service life of an LED luminaire.

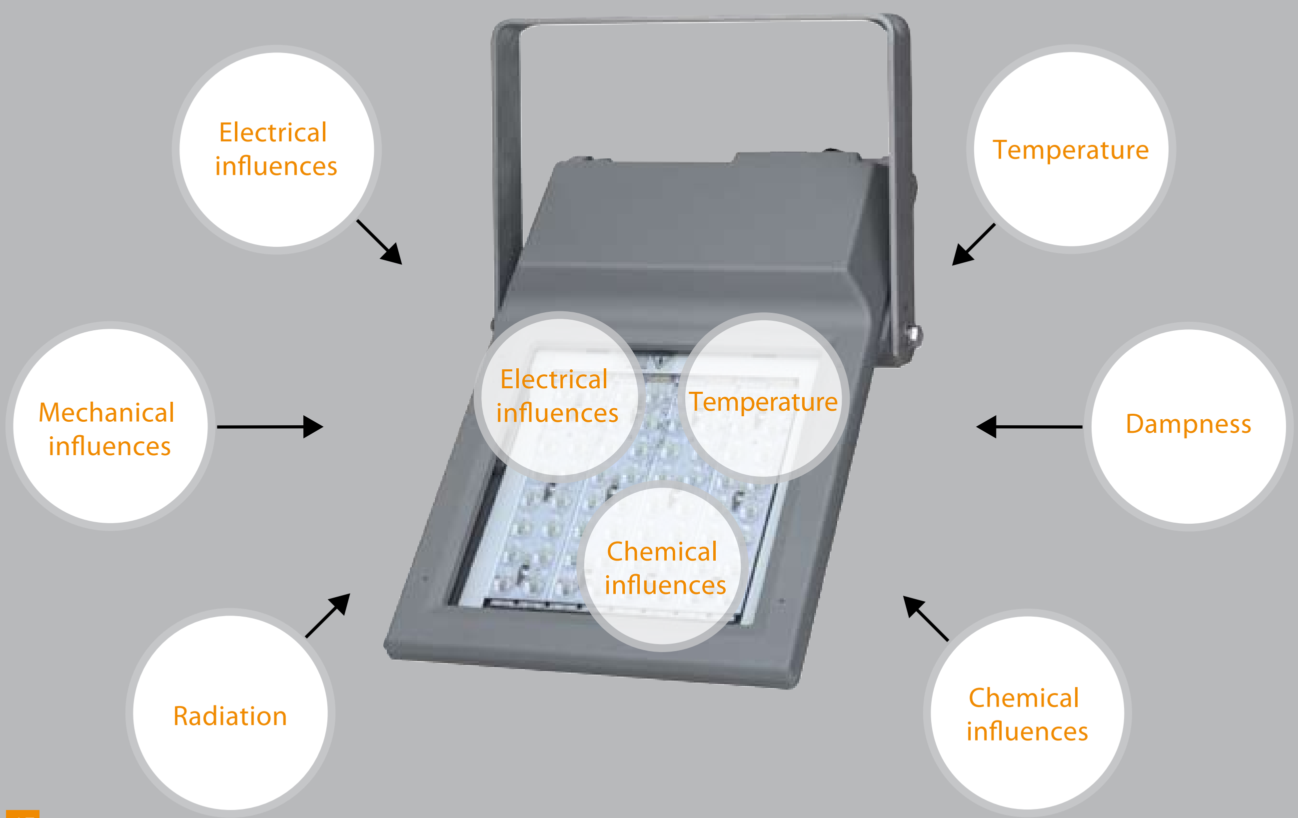
In contrast to conventional lamps, total failures of LED light sources are extremely rare. They are practically maintenance-free once installed in a lighting system. Only the brightness, i.e. the luminous flux, decreases slightly over the operating life. The internal and external factors shown in the diagram on the right [45] have a significant influence on the service life of the LED.

Temperature, thermal management

The most important factor for ensuring the correct operating temperature of an LED is good thermal management. Excessive temperatures have a proven negative influence on the service life and luminous flux of both the individual LED components and the complex LED module. For this reason it is necessary to dissipate the heat from the semiconductor chip by means of design measures, e.g. heat sinks.

Basically, the cooler the temperature at which the LED is operated, the longer its service life and the higher its efficiency. The ambient temperature is also decisive: the warmer it is, the greater the importance of efficient heat dissipation in the luminaire. Reputable manufacturers note the maximum permissible ambient temperature on their products; this allows the optimum luminous flux and service life to be obtained from their LEDs.

Internal and external factors affecting LED service life



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[46 - 48] LED luminaires consist of various technical components, ranging from a PCB and heat sink through to optics and the luminaire housing. All components must be optimally matched in order to ensure a long service life and reliable operation.

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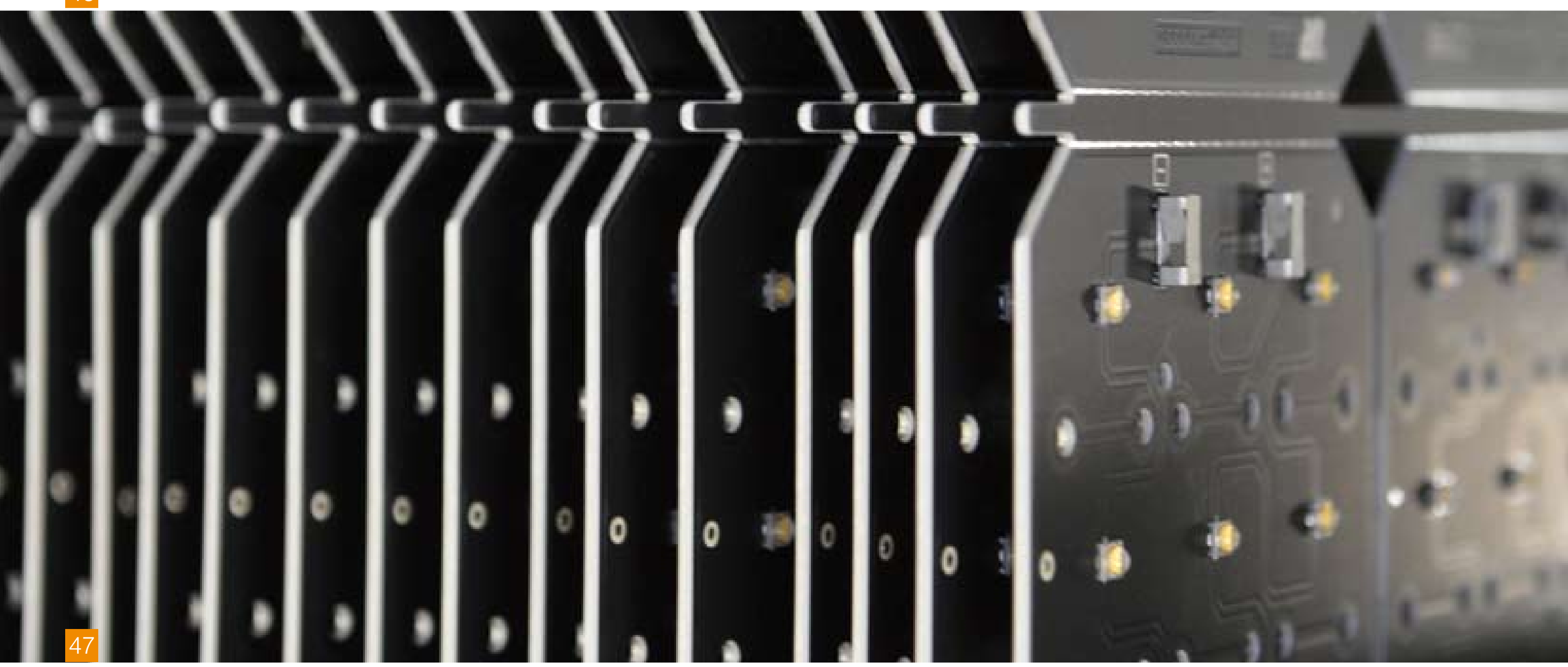

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Radiation and chemical influences

LED luminaires must be made from high-quality materials. They must remain permanently resistant – e.g. to solar radiation and chemical influences (such as salt water by the sea or chlorine in swimming pools). If the materials become brittle, moisture can penetrate the luminaire and damage sensitive electronic components, leading to technical failure.

Mechanical influences

The expected mechanical influences on the luminaires must be identified in advance so that suitable products can be selected during the planning stage. High impact and shock resistant luminaires are required for lighting solutions in sports halls, for example; they must be impact-resistant and unbreakable.

However, outdoor luminaires in public spaces should also be protected as effectively as possible against vandalism, impact and weather (such as hailstorms) and have correspondingly robust and durable housings.

Dampness

Moisture can cause electronic components to fail within a very short time and result in permanent damage. It is therefore important to use high-quality, water- and dust-proof luminaires wherever environmental conditions make it necessary. The suitability of luminaires for certain ambient conditions is determined by the coding which identifies the particular degree of protection. They are indicated by two IP code digits (Ingress Protection). The first figure refers to protection against the penetration of solids and dust, the second describes the protection against water and moisture penetration. IP 44, for example, indicates resistance to foreign bodies > 1 mm and protection against splashes (see table on page 41).

Power

LEDs and LED modules must be operated electronically. This requires a ballast unit which matches the operating characteristics of the module or the LED. Possible external influences, such as overvoltages, must be taken into account and all other technical precautions must be taken to ensure trouble-free operation of the luminaire.

Maintenance, service life, efficiency

The very long life of LED luminaires means that they are virtually maintenance-free. As a rule, it is no longer necessary to replace lamps (as was necessary in the past). In general, the quality of LED luminaires expresses itself in uniform light colours and homogeneous brightness as well as in the long service life of the system as a whole. As described above, good thermal management is particularly important for a long service life.

The LED is a half-space spotlight, the greatest efficiency of which is in the actual direction of application. The optical systems of an LED luminaire produce very precise light control with regard to visual tasks. An LED lighting system therefore permits sustainable gains in overall efficiency.

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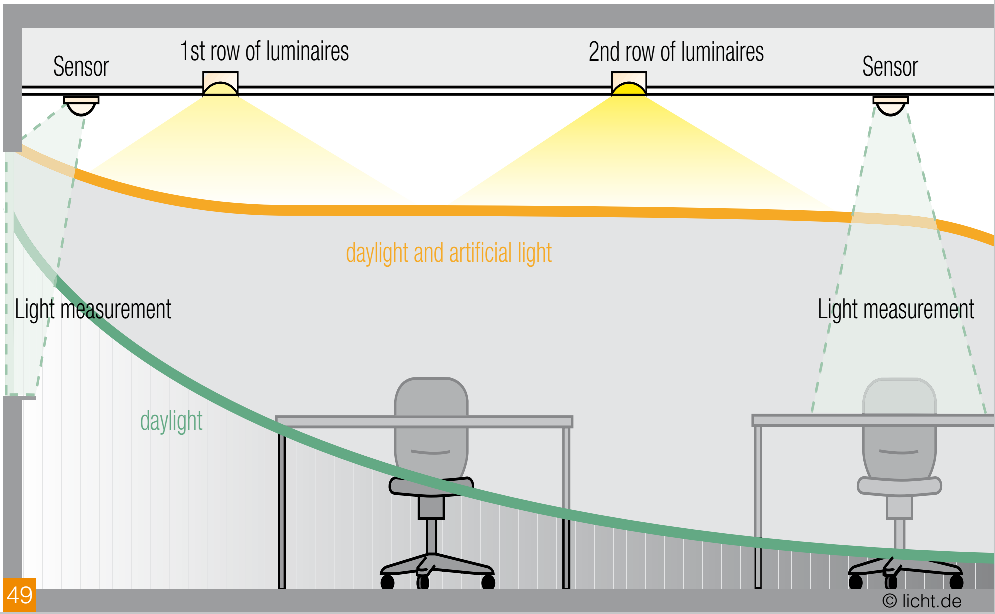
Daylight-regulated lighting



LED lighting control

From simple on/off switching and dimming through to room-based presence- and daylight-dependent activation and fully integrated building control in which all devices exchange information with each other: lighting and building control systems today offer the appropriate solution to meet every need.

[49] Example of daylight-regulated lighting: sensors measure the amount of light required and the luminaires are controlled accordingly.

[50] Today, digital lighting control systems can be operated conveniently and controlled locally or from a central point.

[51] Each building structure is individual and therefore has different lighting requirements. If selected and used sensibly, lighting management systems provide for optimum lighting in a wide variety of spaces and zones.

As flexible electronic components, LEDs are predestined for use with intelligent lighting control systems and greatly expand the range of individual lighting design possibilities. LED technology enables the use of millions of colours and a range of dynamic effects that can create scenes and ambient lighting that would not be possible with conventional light sources. The targeted use of dynamic colour lighting can also have a positive effect on health and increase performance.

Modern control technology offers many “smart” combinations of luminaires with changeable light colours and dimming functions – based on highly developed operating elements, daylight/motion sensors, electronic ballasts and control units. This technology not only controls the light intensity and quality, it also makes a significant contribution to saving energy and integrates all components in a highly targeted manner. It is possible to create precisely the right lighting profile to suit the individual requirements of people with a wide variety of tasks and visual areas – be it for individually optimized workplaces, for an appealing restaurant ambience or for superior comfort in the home environment.

Classic wired technologies in combination with programs such as Digital Addressable Lighting Interface (DALI) and Digital Multiplex (DMX) have proven their value in terms of variable functionality in lighting control systems (especially with KNX for combined lighting and building control systems). Recently, wireless systems such as ZigBee, Bluetooth, W-LAN or LAN/Ethernet have become more popular. It is expected that all electronic or automatic technology components in buildings or public spaces will soon have with their own IP addresses.

Intuitive control

Lighting control systems require intuitive user interfaces. This should be ensured at the planning stage of larger lighting control projects. A “simple” logical interface (e.g. an app for lighting scenarios) makes the control system easy to use. Lighting management systems are, by their nature, technically highly complex. Intuitive controls involving a user interface ensure optimum user-friendliness.

Individual adjustability

Lighting control systems can be fully automatic. For greater satisfaction in workplace environments, however, they must also offer manual options which allow individual users to adjust the light themselves. Older people usually need more light than their younger counterparts; people who mainly work on screens need a different form of lighting to employees in production.

Lighting control - yes or no?

Today, sophisticated lighting and building control systems are taken for granted in new public buildings. Nearly all new buildings have a building management system. EnEV and ISO 18599 provide clear guidelines here. The German Sustainable Building Council (DGNB e. V.) also provides specifications for lighting control systems, albeit only for individual user control. Many systems are still being installed without lighting control systems in modernization projects. Whether such an approach makes sense must be decided on a case-by-case basis. In both new constructions or in modernization projects, it is advisable to take lighting control into account from the initial design phase. Here are some examples of basic considerations:

- What is the scale of the building project? Would a room-based control solution be suitable for smaller projects/a smaller number of rooms? Is the property large enough to warrant a building-based control system?
- Can any predecessor systems be integrated?
- Can the control system be combined with the planned emergency lighting control system?
- How exacting are the demands with regard to the forward compatibility of the building, e.g. for rental units?
- Should the technical standard of the system be upgradable?
- What use is planned for the building?
- In a property containing rental units, should areas that are rarely used be divided up and controlled by their tenants as part of a space allocation plan?
- How flexible must individual work places be? Are frequent changes of use to be expected?
- In terms of operational/space optimization, should areas that are rarely used be split off and equipped with a separate control system?
- Should the luminaire simultaneously collect data on presence/absence, duration/intensity of room use, oxygen/ CO^2 content of room air, temperature, etc., i.e. building automation?
- What level of personal technical flexibility should the users be given?

Optimum solutions

Two questions arise with regard to the best lighting management solution:
1) What tasks should the system perform? – and 2) Where? At the building level, the different application areas – e.g. work place, room and building – are relevant. However, the lighting and control plan is influenced not only by the later use, but also by the architecture of the building. The purpose of a sensibly and aesthetically chosen lighting management system is the optimally accentuated illumination of all room areas and zones. Office space can be divided into work and communication areas with different lighting atmospheres.

The primary task of the lighting management system is to save energy. Thus, the presence of people must be continuously detected. Industrial buildings, for example, contain assembly zones or areas for machines that do not require permanent lighting. The same applies to access areas of buildings, corridors, staircases, toilets, storerooms and warehouses.

Further information on this topic can be found in licht.wissen 12 “Lighting Management”.

Human Centric Lighting

Light is the original form of energy without which life on earth could not have developed. Plants, animals and humans cannot live without light. Many processes in nature, the human body and the human psyche can be positively influenced by natural light.

Light fulfils a wide variety of functions in human beings. The seemingly most elementary is also one of the most fundamental: light enables vision. It helps us to see. Yet light can do much more: it provides a biological impetus. It tells us when we should be awake and when we should sleep, thus helping to maintain and improve our health. Because light is partly responsible for our sense of well-being. After a long winter we long for spring. Our mood lifts as the days lengthen. We are more optimistic, cheerful, active, flexible and focused. So we don't just need light to see well. It has a much more far-reaching significance for us.

The rhythm of our "body clock"

Biologically speaking, we are controlled by a complex metabolic system that coordinates and harmonizes all bodily functions over each 24 hour period - our "body clock". It is oriented towards daylight. If the body clock loses all sense of time because of a lack of light, people develop mental disorders such as listlessness, fatigue, mood and weight fluctuations, or even actual illnesses due to a weakened immune system.

Day and night

Our day-night rhythm, also known as the "circadian" rhythm, controls many organic processes in the body via the hormone melatonin in our blood serum. Melatonin is produced in the pineal gland of the central brain. The more melatonin that is produced, the lower the activity level. Conversely, a high level of cortisol leads to veritable surges of activity. The production of melatonin and cortisol is directly controlled by the amount of light energy incident on the retina – a metabolic process that takes place independently of our vision. A lot of light, especially the short-wave part of the visible spectrum, causes the cortisol level to rise. We wake up! Melatonin production is reduced. When it gets dark again, this process is reversed.

Human Centric Lighting (HCL)

Human Centric Lighting supports human health, our sense of well-being and performance in a targeted and long-term manner through holistic planning and exploitation of the visual, emotional and, in particular, biological effects of light. The modern LED lamps and lighting control systems of special lighting concepts make it possible to use light in a targeted manner that has a beneficial influence on the body clock in the form e.g. of particularly bright light that intensifies our waking phase, or of dynamic light that gives us a feeling for the daily rhythm even in situations when no daylight is visible. The lighting of a room is adapted to the individual lighting needs of its user in order to achieve the maximum benefit from the light or lighting quality.

Potential uses in professional contexts

There are various possible applications for Human Centric Lighting in a professional environment, depending on the lighting requirements and the desired lighting effect.

In the office, it supports people's natural daily rhythm and generates a pleasant performance-enhancing working atmosphere in which the biological preconditions for a restful night are created as evening approaches. Presence detection and efficiency-optimized dimming are also possible.

In the medical field and in care environments, the use of circadian-oriented LED light can be therapeutically beneficial and support a healthy biorhythm. This can help accelerate healing processes.

Error prevention and occupational safety are particularly important **in everyday industrial life and in production**. Shift work can severely impair the sleep-wake rhythm, thus preventing the necessary regeneration. Suboptimal lighting can also represent a work safety risk that can be eliminated with Human Centric Lighting.

Further information on the subject can be found in licht.wissen 19 "Impact of Light on Human Beings" and in licht.wissen 21 "Human Centric Lighting Guide".

[52] The early start to the school day often imposes a sleep-wake rhythm on young people which can have a detrimental effect on their concentration. Lighting-based support for the body clock increases attention levels and enables concentrated work.

[53] The lighting quality criteria are closely linked to the biological, visual and emotional effects of light. All these lighting planning factors must be taken into account in an integrated HCL lighting concept.

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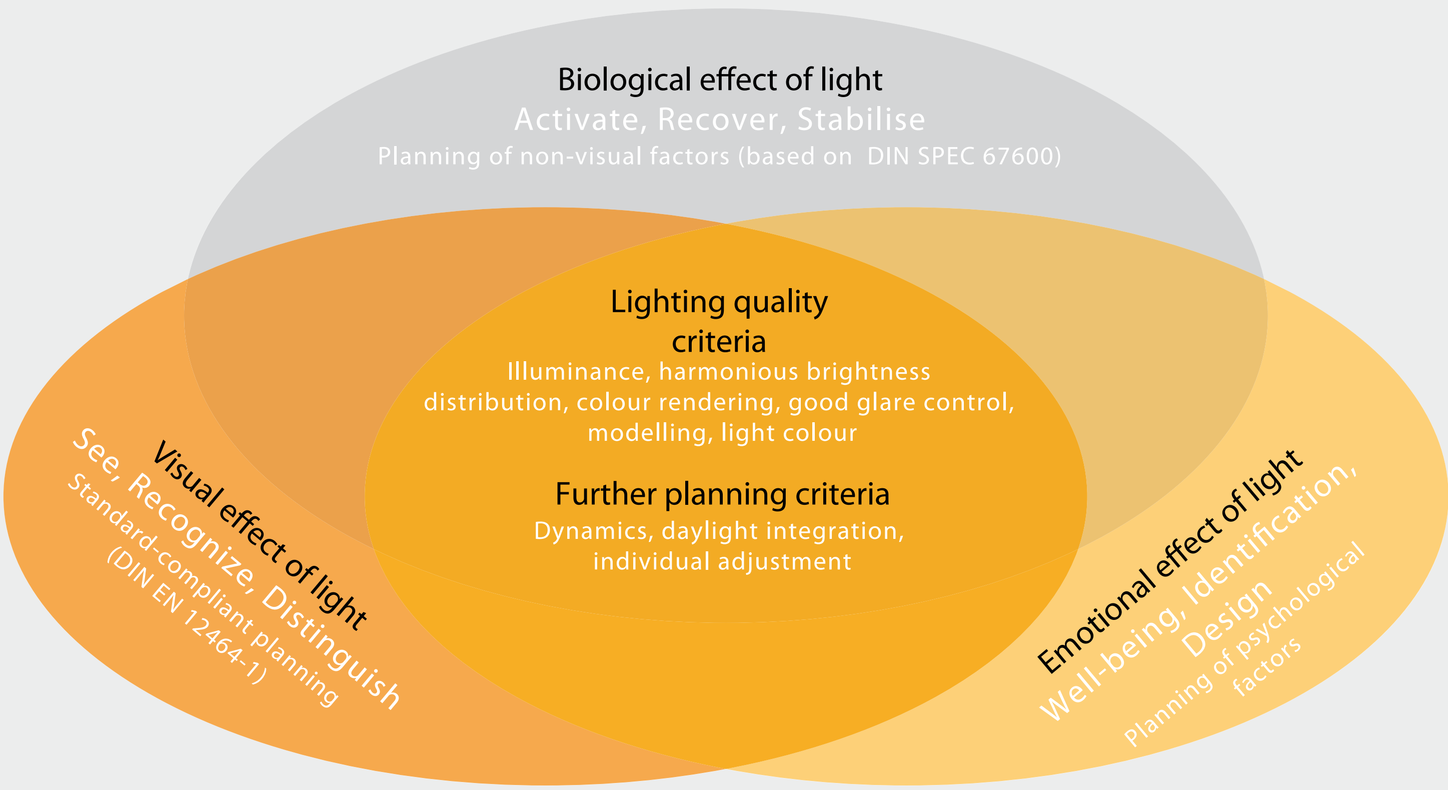
Human Centric Lighting (HCL)



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Safety, marks and standards

Operational safety and flawless quality are paramount for electrically operated products such as ballasts and luminaires. Standards regulate the safety requirements to ensure there is adequate protection against health risks and against fire and commercial losses.

CE mark

The CE mark is a prerequisite for selling products within the European Union. Manufacturers and importers are themselves basically responsible for providing confirmation that their products meet the fundamental requirements of the European directives and protection targets. The abbreviation CE stands for Communauté Européenne (European Community). However, the CE mark is not, as is often assumed, based on a test conducted by a neutral testing body. The manufacturers themselves carry responsibility for performing such tests.

ENEC/VDE test marks

The ENEC test mark (ENEC = European Norm Electrical Certification) is the European test mark for luminaires, ballasts and starter devices, capacitors, converters and transformers, and indicates uniform test conditions. The assigned number identifies the respective testing body. ENEC and VDE marks are usually awarded in combination in the Federal Republic. Consumers can rely on the fact that products which carry these marks contain state-of-the-art technology.

GS mark

Authorized test centres use the GS (tested safety) mark to confirm the conformity of a product with the German Equipment and Product Safety Act (GPSG) or with the relevant EU directive. This includes a functional safety test for the product. In addition, the comprehensibility and completeness of the operating instructions are assessed. The GS mark may only be used in conjunction with the mark of the testing body (e.g. VDE, TÜV). Control measures are carried out to maintain the certificate; these include monitoring the production facilities and checking product changes in comparison to the tested model.

EMC test mark

Electrical devices and electronic circuits radiate or conduct high-frequency electromagnetic energy. This can cause interference which leads in turn e.g. to unwanted noise on the radio or even equipment failure. The inspection body examines whether the freedom from interference stipulated in the Wireless Protection Act is upheld and whether the device is electromagnetically compatible (EMC).

Protection classes

Luminaires and electrical equipment are divided into three protection classes according to DIN VDE 0711, depending on their protection against excessive voltages and accessible live parts:

- Protection class I

In protection class I, users are protected by the live parts being insulated (basic insulation) and by conductive and accessible metal parts being connected to the protective conductor (earthing). The protective conductor terminal is marked with the earth symbol (see above). Even if the basic insulation fails, accessible conductive parts cannot carry dangerous voltages.

- Protection class II

In protection class II luminaires, live parts are given extra protective insulation in addition to the basic insulation. No protective conductor connection is permitted. Even if the luminaires have electrically conductive surfaces, users are protected from coming into contact with live parts through extra insulation.

- Protection class III

The protection of class III luminaires is based on the use of SELV (Safety Extra-Low Voltage). Typical applications include pond or swimming pool lighting. The supply voltage is provided in combination with a safety transformer (or equivalent device).

IP protection classes:

IP protection classes, see table on the right [56], are used to classify the operating safety of luminaires. They are indicated by two IP code digits (Ingress Protection). The first number indicates the ability to keep out solids and dust. The second number describes the level of water and humidity tightness. An example: IP 44 stands for foreign bodies larger than 1 mm and protection against splashes. An X stands for an unspecified code number.

Basic lighting standards

The aim of standardization is to promote the national and international exchange of goods and services and to prevent technical barriers to trade by harmonizing the requirements for tangible and intangible goods. A standard is a rule adopted and published by a standardization body or standardization organization. Norms and standards are the products of standardization and their purpose is to ensure the safety of citizens.

[54-56] Luminaires - especially those used outdoors - are exposed to external influences e.g. in the form of extreme heat, frost or rain. The IP number indicates the degree of protection.

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IP protection classes

Code numerals	**1st code numeral:** Protection against foreign bodies and contact	**2nd code numeral:** Protection against water
0	non-protected	non-protected
1	protected against solid foreign bodies > 50 mm	protected against dripping water
2	protected against solid foreign bodies > 12 mm	protected against dripping water when 15° tilted
3	protected against solid foreign bodies > 2.5 mm	protected against spraywater
4	protected against solid foreign bodies > 1 mm	protected against splashwater
5	protected against dust	protected against jets of water
6	dustproof	protected against powerful jets of water
7	–	protected against temporary immersion
8	–	protected against prolonged submersion ...m

Lighting design for LED systems

The price, but also the fulfilment of defined product criteria and the description of the required lighting quality play decisive roles in the tendering process. Before the contract is awarded, it should be ascertained whether the required quality is also provided during actual operation of the lighting system.

The lighting quality, ease of control, maintenance, service life and sustainability of all offers should be assessed. Unfortunately, there are still suppliers whose products do not fully meet their technical claims. For example, a lighting system that initially appears inexpensive at the planning stage can eventually prove very costly as the result of necessary improvements and revisions.

Uniform definitions and categorizations are therefore indispensable for ensuring the comparability of LED technology. The parameters used for reaching a decision must be objective. Only thus can application-oriented criteria be created that enable reliable assessment and standardization of the various products and qualities.

Comparison criteria for LED lighting systems

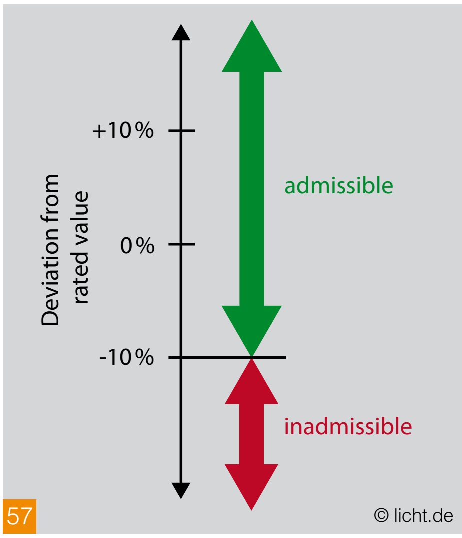
The following characteristics based on IEC standards regarding their mode of operation are suitable for making a formal comparison of luminaires and their technical performance:

1. Rated input power P

The input power of a luminaire is the power consumed (in watts), including all internal consumption. The rated input power is a quantity that applies to the entire production range of this type of luminaire when new, including the tolerance deviations of all installed components. The rated input power of an LED luminaire is documented (usually in watts (W)) on the type plate, on the LED data sheet and in the electronic data. This value can reliably be used for further assessments and calculations.

2. Rated luminous flux of luminaires Φ_v

The rated luminous flux of a luminaire is the initial value of the total luminous flux (in lumen, lm) which is emitted in all directions in the visible range under certain operating conditions (at 25° C). The rated luminous flux of the reference luminaire should be no more than 10 % below the measured initial value of the luminaire. The rated luminous flux is documented in the corresponding data sheet and in the electronic data.



3. Luminous efficacy of LED luminaires η_v

The luminous efficacy (in lm/W) is the ratio of rated luminous flux to rated input power. Only in comparable luminaires with similar luminous intensity distributions can luminous efficacy be used as a criterion for comparability or for evaluating energy efficiency. In all other cases, separate calculation of the lighting system is necessary.

$$\eta_v = \frac{\Phi_v \text{ of luminaires in lumen}}{P \text{ of luminaires in watts}}$$

[58] Different systems can only be compared if identical selection criteria are used. During the luminaire selection process, it is also advisable to make an optical comparison of the lighting effect using sample luminaires.

[59] Key criteria for street lighting are uniform illumination of the street and the avoidance of dark zones.

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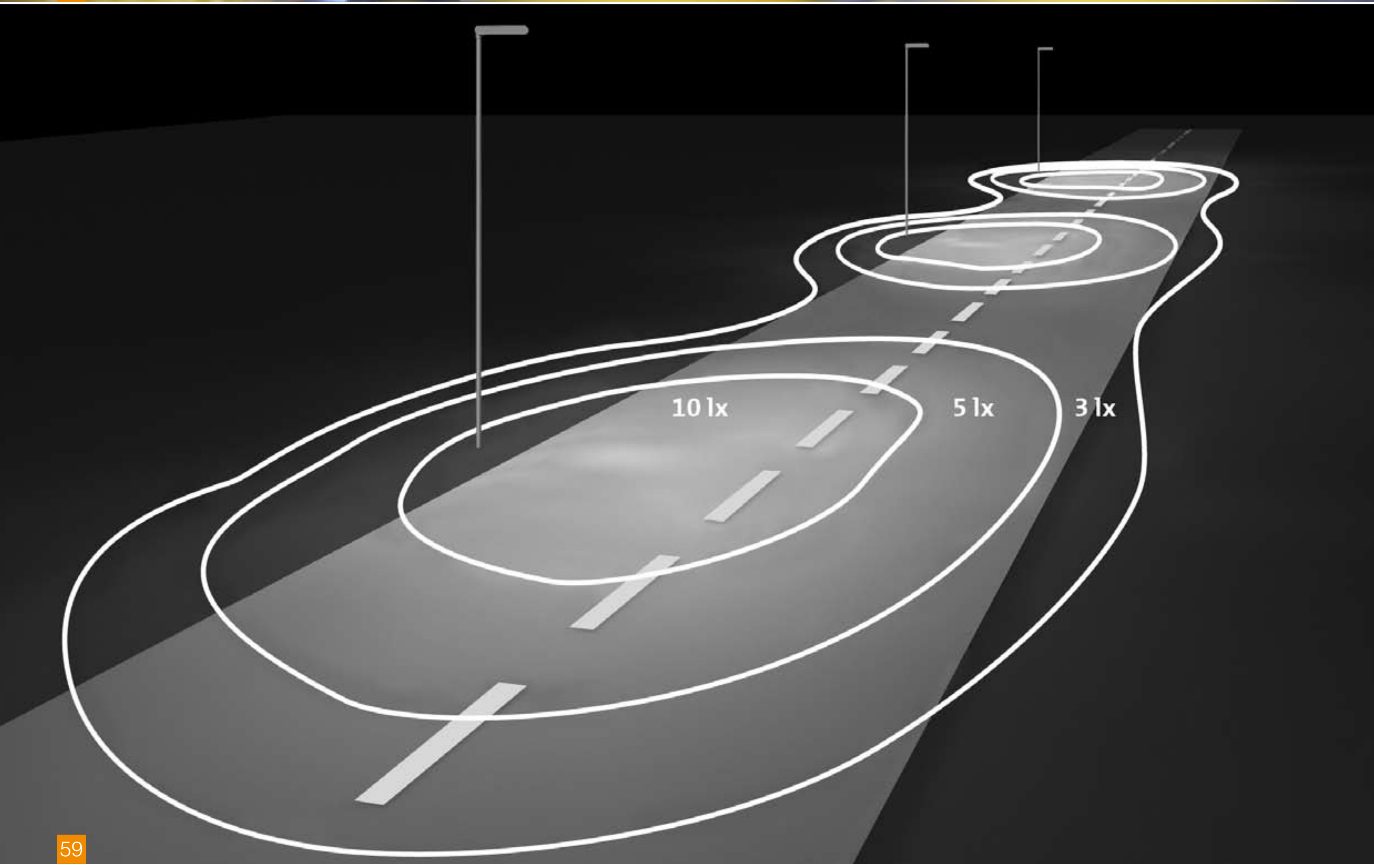

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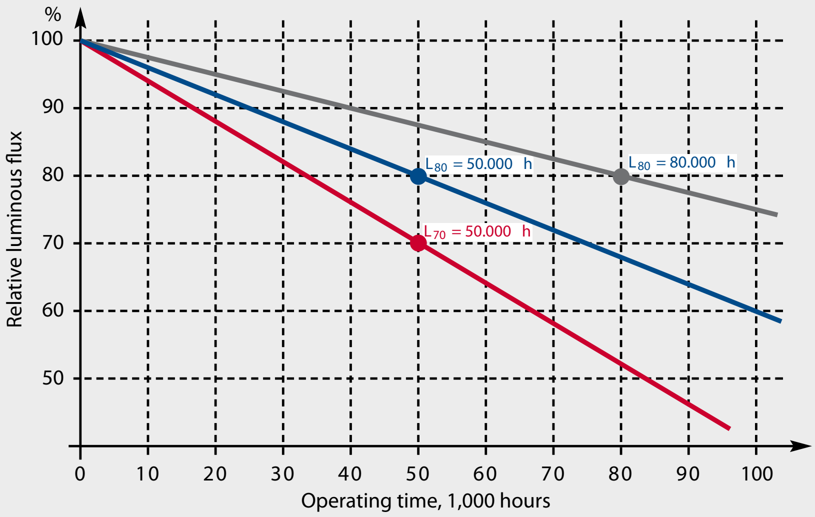
Graph showing light over service life



60 Simplified representation

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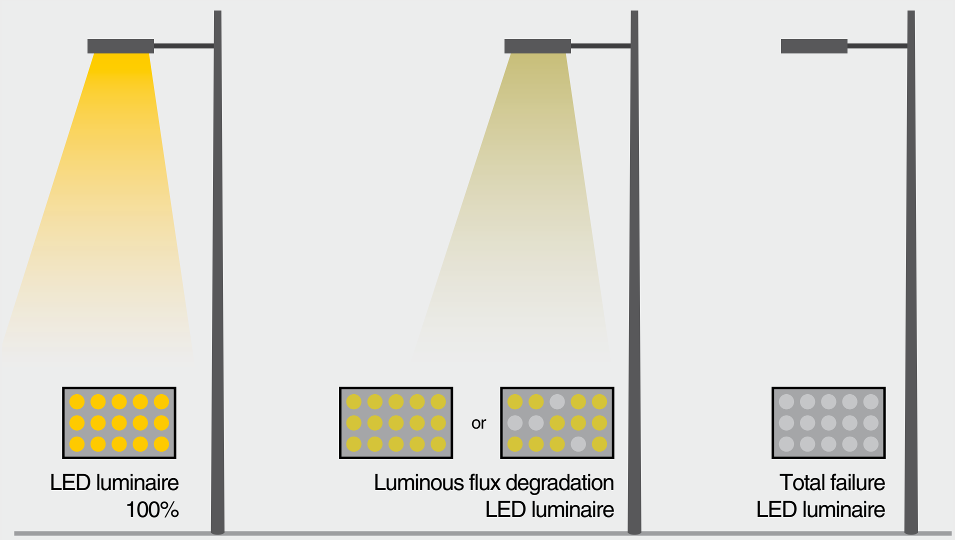
Luminous flux decline until total failure



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CLO – Constant Light Output

The luminous flux emitted by LED luminaires diminishes over time as a result of the ageing process. That is why lighting systems must always be oversized during the lighting design stage. This ensures that the value does not fall below the illuminance level of the maintained value towards the end of the service life. This type of dimensioning has the disadvantage of generating undesirably high luminous fluxes at the beginning of the service life, and therefore wasting energy. The CLO - Constant Light Output - principle is applied in order to save this energy. The energy supply is raised continuously over the service life, meaning that 100% of the required illuminance is generated at all times. This counteracts the fall in luminous flux of the luminaire. Accordingly, no oversizing is necessary at the beginning of the operating phase, thereby allowing energy to be saved.

4. Luminous intensity distribution of LED luminaires

The spatial distribution of the luminous intensity of light sources and luminaires is described in luminous intensity distribution curves, as shown in Figure 63, based on the example of an indoor luminaire. The exact values of the luminous intensity distribution of an LED luminaire in the room are recorded in the lighting planning documents.

5. Colour quality of LED luminaires

The colour quality of white light is defined in terms of the following properties: light colour, described using the most similar colour temperature; colour rendering, described using the colour rendering index; colour tolerance, described using MacAdam ellipses. Further information can be found in the “Quality features of LED light” chapter (pages 22-25) of this booklet.

6. Rated ambient temperature and thermal management

The operating behaviour of LEDs is strongly influenced by the ambient and intrinsic temperature. High temperatures reduce the luminous efficacy and service life of LEDs. For this reason, the thermal management of luminaires must be given special consideration during the planning. The rated ambient temperature t_a (ambi-

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ent) determines the temperature at which the luminaire can be operated in compliance with the safety-relevant parameters.

7. Service life criteria of LED luminaires

The service life of LED luminaires can be shortened in a wide variety of ways. Spontaneous functional failure is only one possibility. Over time, the brightness of the luminaires gradually decreases. Falling below the predefined minimum luminous flux is also referred to as degradation. The fall in luminous flux can also be caused by the failure of individual LEDs or LED modules, large numbers of which may be fitted depending on the design of the luminaire (ballast failure is excluded here).

Maintenance and service life of LED luminaires

In addition to the above comparison criteria, two other factors are particularly relevant for good planning: the expected service life and the associated maintenance factor of the LED luminaires. In order to obtain a characteristic figure for these values, LED luminaires are classified with regard to their luminous flux behaviour.

The factors service life, degradation and total failure are also analysed. These properties are encoded using the letter sequence $L_xB_yC_z$. L_x specifies the life span (e.g. 50,000 h) during which percentage x of the original luminous flux of the new product is reached. By specifies the percentage of LED luminaires which fall below the target as-new luminous flux (L_x) at the defined end of their service life. C_z refers to the percentage of completely failed luminaires.

Example: An LED luminaire is marked L_{80} B_{50} C_0 = 75.000 h. This means that after 75,000 hours, only 50 per cent of the still functioning luminaires provide a luminous flux which is less than 80 per cent of the initial value. If no B value is specified, B_{50} applies. This means that half of the luminaires still have at least 80 per cent of the initial luminous flux after x hours.

Durable product properties - high quality standards - low maintenance costs

The standardization of quality values in the above areas is very useful in order to select the “right” product at the lighting planning stage. Comprehensive assessment of the quality and sustainability is only meaningful and possible if, in addition to the price, the available products and planning drafts are also checked using the above criteria.

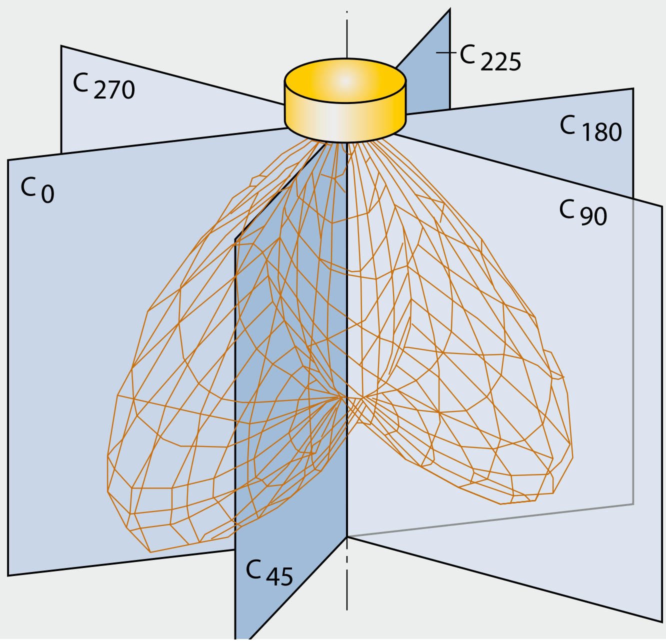
[60] The light output of LED systems decreases over time. The service life is given as L_x. Typical examples of the proportion x (as %) of the rated luminous flux are e.g. 70 or 80 per cent (= L_{70} or L_{80}) at a given rated service life of 50,000 hours and an ambient temperature of 25° C for the luminaire.

[61] LED luminaires gradually lose brightness over a period of several years, with the luminous flux only declining imperceptibly. It can take decades until the luminaire fails completely. It is decisive here to have a maintenance plan and to organize timely replacement of the components.

[62] Smart lighting technology can be used to dim and switch luminaires and also to determine their photometric values.

[63] The measured light distribution values are displayed graphically in luminous intensity distribution curves.

Luminous intensity distribution curves of an indoor luminaire



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Identifying potential savings

Although obsolete luminaires can easily be identified from their design and equipment, it is not possible to quantify the power consumption and maintenance costs caused by the obsolete technology. The high energy consumption and maintenance costs of an old system yield correspondingly large savings potential for modernization projects.

[64] This sample checklist – limited to visual parameters only – provides a very general overview. Meaningful statements on refurbishment and potential savings are only possible with extended checklists that also include the technology, energy and illumination values of the system.

Modernize or replace?

The decision of whether a lighting system should be modernized or replaced is based on the maintenance schedule and the systematic recording, documentation and analysis of all components.

Two factors are decisive here:

1. Is the system, including its lamp and luminaire types, still of high enough quality? Is it still optimally suited for its purpose and does it still permit all visual tasks to be performed?
2. Does the system have acceptable energy and maintenance levels? Are the operation and maintenance costs still competitive?

Such detailed data permits a qualitative and technical evaluation of the (old) system – and thus a meaningful presentation of the modernization options and the associated economic effects as part of a professional consultation. Of course, the many different targets of potential corporate investment always have to be weighed against each other. However, if the lighting system is in poor condition, modernization should be a high priority. Poor illumination of work places can have negative consequences for employees and work quality, and therefore modernization should not be postponed.

Systematic approaches

The systematic qualitative evaluation of a system provides an initial indication of which measures are necessary and which work steps should be prioritized.

Checklists: Standardized checklists represent effective tools which enable planners and installers to structure analysis processes more efficiently. During the consulting process, they help to identify areas of potential savings. And they not only compare measures objectively (in terms of performance and cost-effectiveness) but also document them for contractors and clients in a comprehensive and legally binding manner. Checklists are dynamic constructs. They can be modified to suit customer requirements, as widely varying parameters apply in different customer segments (office, retail, industry, trade, etc.) both in terms of content and detail.

Digital capture: All data collected should be processed electronically (e.g. in tabular form). This allows it to be updated without major effort at any time, thus yielding an up-to-date overview. This is particularly helpful for larger modernization projects in which system conversion is carried out in several steps and over several years.

Parameters: The analysis lists record all relevant conditions of the existing system: room size, operating hours and room conditions (such as daylight incidence and reflectance), technical data on lamps, luminaires and lighting geometry, but also parameters regarding staff presence levels and flexibility during expected conversions. Economic factors, such as electricity prices and growth rates, are also included here.

Measurements: Only high-quality professional measuring devices (e.g. lux meters) should be used. Simple smartphone apps are not recommended (they can yield significant deviations and errors). The aim of the measurements is to determine whether the system still complies with the standard. Whether or not the existing system has been reliably maintained must be taken into account. If not, simply cleaning and replacing the light sources can double the initial measured value. Only then can the need for modernization be accurately assessed.

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Check list: Identifying potential savings

Name of customer:	
Address / Property:	
Entered by:	

How efficient is your lighting system?

Even if only one box is ticked, there are potential savings to be made!
The more criteria which are met, the greater the potential savings.

Is the system more than ten years old?	☐ Yes
Is the annual operating time more than 2,500 hours / the daily operating time ≥ 10 hours?	☐ Yes
Does the system still contain lamps that are now banned throughout the EU, e.g. incandescent lamps or high-pressure mercury vapour lamps?	☐ Yes
Are the luminaires still equipped with conventional metal/copper control gear (transformers, ballasts)? (Note: Fluorescent lamps with conventional ballasts can be recognised by taking a picture of the luminaire with your mobile phone. If stripes appear in the camera display, conventional control gear units are fitted.)	☐ Yes
Are there	
Opal diffuser luminaires with fluorescent lamps?	☐ Yes
Luminaires with white louvres and fluorescent lamps?	☐ Yes
Indirect light luminaires with fluorescent lamps or compact fluorescent lamps?	☐ Yes
Downlights with compact fluorescent lamps?	☐ Yes
Luminaires with halogen lamps?	☐ Yes
Is the price of electricity more than 18 cents/kWh?	☐ Yes

Recommendation

Have you answered yes more than three times?
▶ Your lighting system consumes far too much energy and should be modernized as a matter of urgency! Get advice and seize the opportunity to make major savings.

Have you answered yes once or twice?
▶ Your lighting system needs to be optimized. Get advice on what measures can be taken to increase energy efficiency which will help reduce your monthly electricity costs.

LEDs – Costs, benefits, quality

The people responsible for making the decisions are often unfamiliar with the opportunities and possibilities offered by modern lighting systems. In many cases they are uncertain of the technical aspects and ignore qualitative and sustainable criteria such as lighting quality, maintenance and user comfort and tend to base the decision primarily on price. Newer service models take this into account: they offer “lighting service” for a monthly fee without any major pre-investment – making it as simple as paying for mains electricity.

Lighting systems yield further benefits

Unfortunately, lighting systems today are primarily evaluated on their cost aspects. Funding is provided for what is necessary to meet the standard values for visual tasks. However, a high-quality lighting system creates many benefits for operators and investors, e.g. through reduced operating costs and the possibility to write down the investment. The low CO_2 emissions benefit not only the environment but also the company’s environmental footprint. And finally, good lighting – which is tailored to the visual tasks at hand, individual visual performance and the room environment – yields health benefits for employees and raises efficiency.

The profitability of lighting systems

Modern and efficient technologies are the key to making substantial savings of up to 60% and more, depending on the technology. Every watt saved means cash – up to € 0.72 based on 4,000 hours of use per year and 0.18 €/kWh (see chart no. 66, right). For example, replacing obsolete suspended luminaires with an individual lamp output of 250 watts and a system output of 274 watts with a new LED solution in a factory would result in annual savings of around 120 euros per luminaire based on a consumption of around 110 watts. Considering the life cycle costs of a lighting system, e.g. over 10 years taking investment, installation and maintenance costs into account, this would result in cost reductions of up to € 500 per luminaire! This represents a return of around 5 -10 %. New lighting systems therefore constitute a very good and safe allocation of resources.

It should be pointed out, however, that such calculations are sweeping generalizations. The difficulty for the decision-makers lies in the detail: only part of the calculation of life cycle costs that are projected over longer periods can be fact-based. Some of the figures are based on assumptions about future developments. From an economic point of view, this means a certain degree of uncertainty and fluctuation.

It is even more difficult to take into account not only the quantitative values but also the costs for such (often highly subjective) values as “quality”. The cost groups must be broken down into factors that have a direct impact on the users, such as the ease of operation of a lighting control system, in contrast to its benefits for the facility manager who thus gains full control over the use of light in a room at all times and confirmation that all luminaires are functioning correctly.

Unfortunately, many logistical decisions have to be made under great time pressure. This makes it difficult to consider superior quality alternatives (with greater sustainable value for the environment, an individual profile and a long service life) which ultimately yield a higher return compared to options which at first glance seem cheaper.

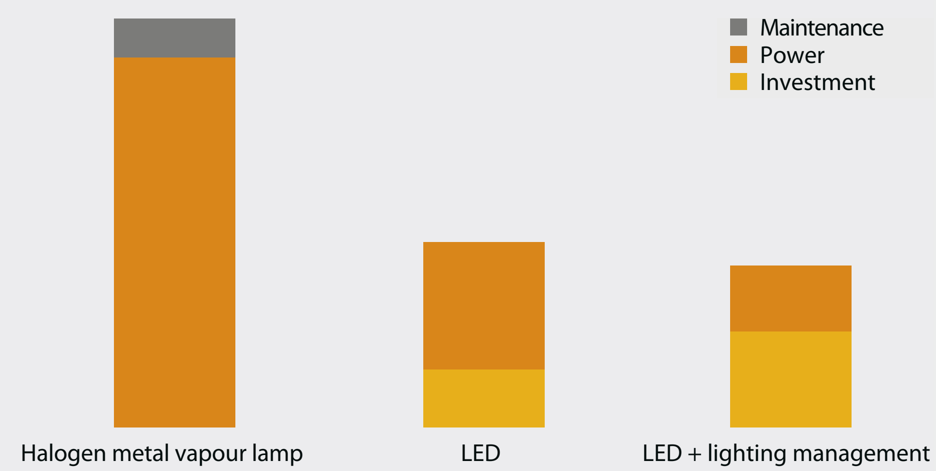
Decision-makers are well advised to consider the relevant criteria for a lighting system in advance and to seek comprehensive guidance from lighting planners. In addition to the lighting quality of a system, criteria such as product quality and more long-term economic factors (such as the service quality of the provider, the maintenance requirement of the system and its service life) should also be taken into account.

Lighting as a service product

An alternative to investing in a system is purchasing “light as a service”. A qualified service partner ensures the effective operation of a customized lighting solution, but also covers the system failure risks. Tailored to the customer's requirements, an individual agreement is drawn up between the partners, e.g. over a lifecycle, which provides security for both sides. For the decision-makers, this means more than just receiving rapid assistance when problems arise: since LED technology is constantly developing, the customer automatically benefits from any advances. Service packages are contractually agreed between customers and suppliers, so-called "lifecycle contracts", which include regular updates and consulting services for technical, material and software innovations.

This solution has advantages for customers. They purchase their light on a flat-rate basis without investing in specific products that require regular maintenance. The amount of effort involved for them is thus negligible, allowing them to concentrate on their core tasks.

Sample analysis of lighting costs of an industrial building* over 10 years



* Industrial building 30 x 50 m / 300 lux illuminance / 3,000 operating hours per year

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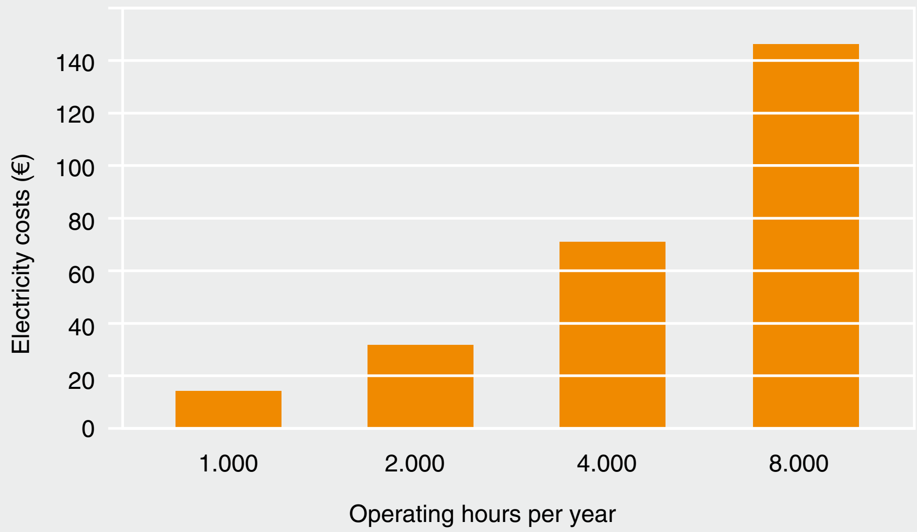
Lighting costs for 100 watts, at electricity price of € 0.18



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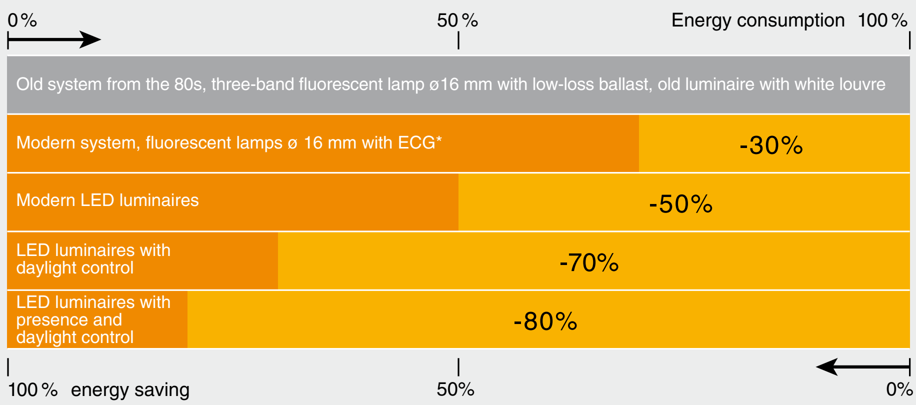
Potential savings in interior lighting



Example based on 2-unit spacing office
* Fluorescent lamps with low power dissipation, luminaires with modern light guiding

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[65] The "Factory lighting costs" graph shows what electricity and maintenance costs can be saved by converting to LED.

[66] Energy savings have a positive effect on the company's environmental footprint and also save money.

[67] Overview of potential savings for interior lighting, based on different technologies.

Advantages of LED lighting

Today, LEDs offer users a multitude of advantages and much greater flexibility than was previously possible in lighting: temporally through variable lighting qualities at different times of the day, spatially through the targeted control of lighting, and on a user-dependent basis through the provision of the right lighting for different user groups.

Efficiency

- High efficiency
- Low power consumption

Light quality

- Good colour rendering
- Directed, easily guided light

Lighting design

- Adaptation of light colour (warm white, cool white, etc.)
- Coloured light
- Control without loss of quality
- Directed, easily guided light
- Greater flexibility and planning freedom
- Light scenarios are easy to program and apply

Design advantages

- Compact constructions for flexible design
- Wide range of design options and variety of forms

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Technology

- Infinitely dimmable
- Smart control
- Impact and vibration resistant

Costs

- Lower energy costs
- Lower maintenance costs

Environment

- No mercury or other hazardous substances
- Simple disposal
- Low CO_2 emissions
- No UV or infrared radiation
- Low insect attraction of outdoor lighting

Durability

- Service life of 20,000 to 50,000 hours and more
- Low maintenance
- Very low total failure rate

Glossary

Lighting technology parameters

The total visible light output of a light source in a room corresponds to the **luminous flux Φ**. Measured in lumens (lm), this takes into account the sensitivity of the human eye to brightness.

The **luminous efficacy η** is the ratio of luminous flux to electrical power consumption and thus a measure of the energy efficiency of a light source. The unit of measurement is lm/W. When making lm/W-based comparisons of luminaires, the losses caused by ballasts must also be taken into account.

Luminous intensity I, measured in candela (cd), indicates the amount of light emitted in a given direction. It is defined as luminous flux per solid angle and is influenced by light-directing elements such as reflectors. The luminous intensity distribution curve (LDC) indicates the light emission behaviour of a particular luminaire.

Luminance L is the measure of the impression of brightness created in the eye by a luminous or illuminated surface. Luminance is measured in candela per unit area (cd/m²), and usually in cd/cm² for light sources. It describes the physiological effect of light on the eye and is used as a planning parameter for outdoor lighting.

Illuminance E, measured in lux (lx), defines how much luminous flux (in lumens) falls on a given surface: it is one lux if one lumen of luminous flux evenly illuminates an area of one square metre. Example: a normal candle flame has an illuminance of about one lux at a distance of one metre. This figure is important in the dimensioning of interior lighting. The standards DIN EN 12464 Parts 1 and 2 “Light and lighting – Lighting of indoor and outdoor workplaces” specify appropriate values.

Reflectance ρ

Reflectance indicates the percentage of luminous flux reflected by a surface. The reflectance of pale surfaces is high, that of dark surfaces low. The reflectance of white walls and ceilings is ρ = 80 per cent.

Glare

Glare can make vision considerably more difficult. It reduces visual performance (physiological or disability glare) and visual comfort (psychological or discomfort glare). A distinction must be made between direct and indirect glare: direct glare is caused by luminaires or other surfaces with excessive luminance, such as windows. Reflected glare has an indirect effect, produced by reflections on shiny surfaces.

To limit glare, the glare source must be shielded and less reflective materials used.

Shadows and modelling

The luminous intensity, direction of light and shadows must harmonize to ensure that objects such as sculptures, reliefs and textures can be recognized and perceived three-dimensionally. In modelling, there is a balanced ratio of diffuse to directional light.

Maintained illuminance

The maintained illuminance is the value in lux related to a given surface, below which the average illuminance should not fall. Wear, dirt and ageing of lamps, luminaires and rooms reduce illuminance. New systems must be dimensioned with higher illuminance levels (illuminance on installation) to compensate for this reduction. This decrease is built into the planning in the form of the maintenance factor:

Maintained illuminance = maintenance factor x illuminance on installation.

Maintenance factor MF

The maintenance factor is defined as the ratio of maintained illuminance to initial illuminance value. It is calculated from the product of lamp lumen maintenance

Good colour rendering

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Poor colour rendering

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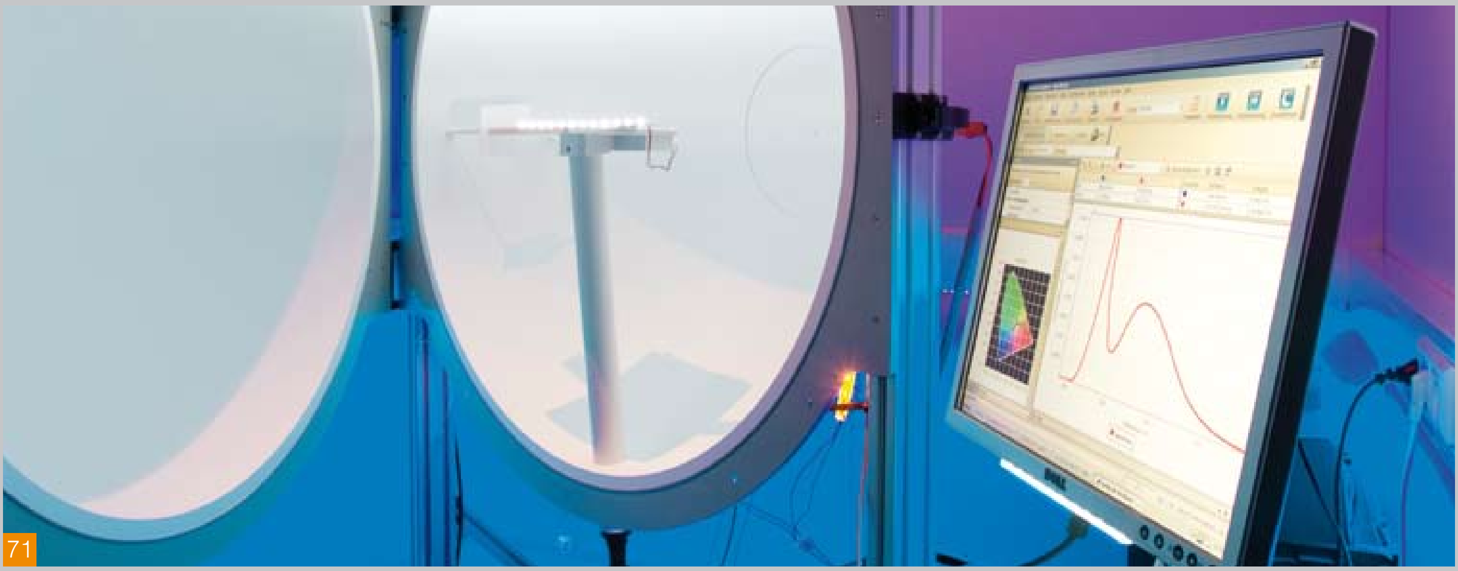

factor LLMF, lamp survival factor LSF, luminaire maintenance factor LMF and room maintenance factor RMF.

Light colours
The light of each light source has its own colour, the so-called light colour. It is described in terms of its colour temperature, measured in kelvins (K). Low values represent warm-toned lighting, higher values indicate cooler lighting. Light colour can be divided into three categories: warm white (colour temperature below 3,300 K), neutral white (between 3,300 K and 5,300 K) and daylight white (over 5,300 K).

Colour rendering
The colour rendering value R_a depends primarily on the spectral composition of the artificial light and indicates the reproduction of colours under artificial lighting in comparison to a reference light source. An R_a value of 100 indicates very good colour rendering. Modern LED light sources achieve very good values.

Contrast
Contrast is the difference between the luminance or colour of two objects or an object and its background. The difficulty of performing a visual task increases with decreasing contrast.

Contrast rendering
Criterion for limiting reflected glare. Contrast rendering is indicated by the contrast rendering factor (CRF) which defines the ratio of luminance contrast under given illumination to luminance contrast under reference illumination for a particular visual task.

Spectral composition of light/ optical radiation
The light spectrum is as follows: UV>Blue>Green>Yellow>Red>IR. The higher the energy of the radiation, the shorter the wavelength. LED light sources emit almost no UV or IR light.

Binning
Slight manufacturing deviations in the production of LED chips can cause the photometric properties to vary: e.g. colour, luminous flux and forward voltage. The LEDs in each batch must be sorted to ensure constant lighting quality with a homogenous brightness level and uniform light colour. They are sorted into so-called “bins”. This binning process is particularly important for white LEDs.

MacAdam ellipses
Today, LEDs are sorted based on the ANSI standard (ANSI C78.377-2011.). This defines colour value deviations using MacAdam (or SDCM = Standard Deviation of Colour Matching) ellipses. These describe the colour distances on the XY coordinates. The MacAdam ellipse indication informs users of the extent to which the light colours of individual LED modules differ from each other. LEDs in these narrowly defined bins guarantee uniform light colour, for example 2,700 kelvins for warm white.

[69, 70] The light source must have good colour rendering in order to reveal colours accurately. Poor colour rendering makes this bouquet appear dull.

[71] The integrating sphere collects the unevenly distributed luminous flux from all directions in order to measure the luminous flux (using a photometer).

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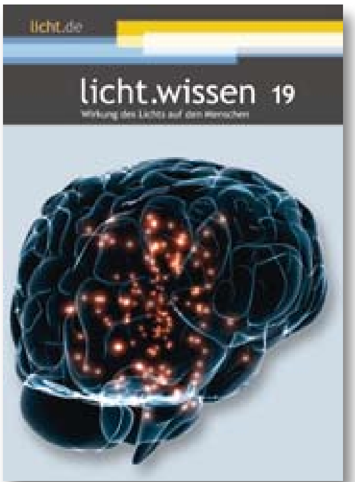

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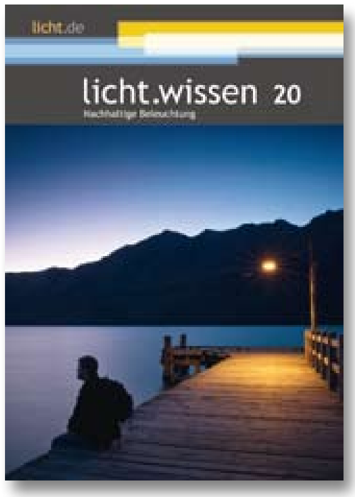

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licht.de provides information on the advantages of good lighting and offers a great deal of material on every aspect of artificial lighting and its correct usage. The information is impartial and based on current DIN standards and VDE stipulations.

licht.wissen
licht.wissen provide information on lighting applications. The themed brochures use plenty of practical examples to explain the basics of lighting technology and present exemplary solutions. In this way they facilitate cooperation with lighting and electrical specialists. The lighting information contained in all of these booklets is of a general nature.

licht.forum
licht.forum focuses on topical lighting issues and trends. It is a compact specialist periodical published at irregular intervals.

www.licht.de
The support association also presents its comprehensive information on lighting on the Internet at www.licht.de. Architects, designers, lighting engineers and end consumers have access to around 5,000 pages of practical tips, details of a host of lighting applications and up-to-the-minute information on light and lighting. An extensive database of product overviews provides a direct link to manufacturers.

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Fördergemeinschaft Gutes Licht
Lyoner Straße 9
60528 Frankfurt am Main
Germany
Tel. +49 (0)69 63 02-353
Fax +49 (0)69 63 02-400
licht.de@zvei.org
www.licht.de