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## LED: The Light of the Future

01

# Editorial

*The LED heralds a new age of lighting – it beats every other option hands down. Its wide scope for application, its flexibility in terms of shape and colour dynamics, its outstanding efficiency and longevity make it the lighting tool of the future.*

*LEDs address both indoor and outdoor applications, making for a new quality of lighting in offices, foyers and homes, on facades and fabrics, in streets and automobiles. The possibility of fine-tuning colour and light temperature to suit the time of day and meet particular requirements makes LED light an everyday tool in hotels and shops, museums and theatres, industry and trade, and at the workplace. Variable LED light is used by doctors to optimise a wide range of examinations, sets a dramatic and brilliantly colourful stage for concerts and TV shows and permits problem-free presentation of sensitive merchandise in infrared- and UV-free light.*

*All these fascinating applications are addressed with extremely high efficiency and longevity. Anyone who opts for LEDs gets green technology that is easy on the budget. Containing no mercury, economical on power and virtually maintenance free, every LED makes a contribution to environmental protection. Where conventional lighting is replaced by LEDs with intelligent lighting management, the energy required for lighting is reduced by around 70 percent. This makes for massive carbon savings and provides an incentive for all sides to help vigorously drive forward the further development and implementation of LED technology.*

*In Germany, the Federal Ministry of Education and Research (BMBF) promotes LED technology in a variety of ways as part of the country's "High-Tech Strategy". Alongside basic research projects, it has launched an LED lead market initiative and introduced a competition under the banner "Municipalities in New Light". The lead market initiative, which draws on the expertise of the leading actors of the lighting industry, is designed to bring together partners to establish LED in general lighting and carry forward the new business models required. The aim of the competition is to promote the use of LED by paying tribute to the top ten municipal demonstration projects.*

*People do not buy what they do not know, so it is essential to get more information about the new technology into the public domain. This booklet will help do just that. Highlighting the unique advantages and applications of LEDs, it shows the scope for design and presents ideas for improving our "light climate".*

*The spectrum of information is rounded off by articles looking at the way LEDs work, the lighting management options they offer and the technical applications they can address – as well as real-life examples of LEDs in use. These insights into the new technology will broaden our perspective of the world of lighting and pave the way for new and original ideas for the light of the future.*

*Read this booklet and discover new worlds of light!*

*Andreas Kletschke*
*Assistant Ministerial Counsellor*
*Federal Ministry of Education and Research*

# Contents



[02] LED spots set the stage for the organic curves of the concrete walls. With a lighting management system, mood images can be produced in RGB colours.

02

03

# LED: The Light of the Future

Light-emitting diodes are the shooting stars of lighting. Tiny and extremely efficient, they are revolutionizing the world of light – delivering a whole new quality of lighting, addressing an ever growing number of applications and saving a great deal of energy. LEDs are the light of the future and are conquering the realm of general lighting.

Whether indoors or out, decorative or functional – LEDs (light-emitting diodes) permit solutions today that would have been inconceivable even a few years ago. Starting out as a coloured signal indicator, the energy-efficient semiconductors advanced rapidly to become one of the principal light sources for accent and orientation lighting. With white light and intelligent management, LEDs now ensure a high quality of lighting right across the range of outdoor and indoor applications.

LED technology is regarded as the most important invention in the history of lighting since Edison's development of the "light bulb" over a hundred years ago. Never before has so much light come from such a small fitting; never before have light sources worked so reliably for so many years and consumed so little electricity. Even recently, attention still focused on the richness of colour achieved by LEDs; today, high-performance LEDs are transfiguring general lighting.

The many positive characteristics of the light-emitting diode include:
> extremely long life and virtual freedom from maintenance
> high efficiency
> white and coloured light with good colour rendering properties
> insensitivity to vibration
> light with almost no heat generation, no IR or UV radiation, no interference with nocturnal insects
> instant, flicker-free lighting that is infinitely dimmable
> very compact design
> no mercury content and no end-of-life disposal problems.

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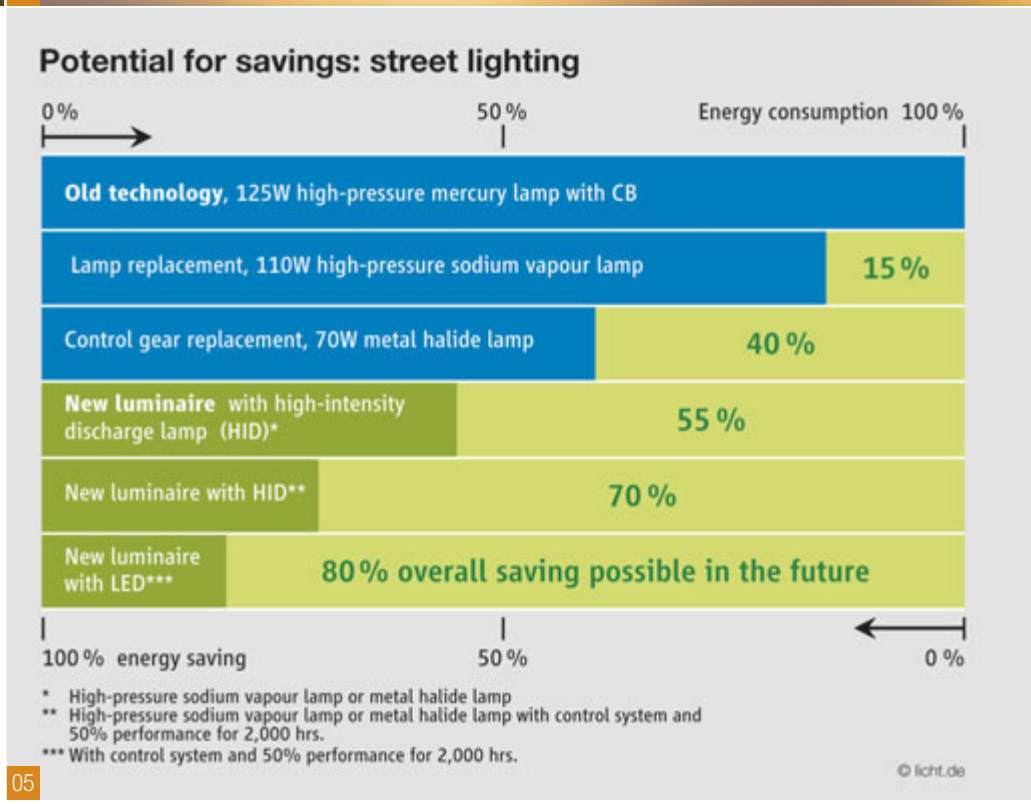


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**LEDs are long-lived and efficient**

LEDs have an operating life of 50,000 hours or more. That amounts to six years of maintained operation or 45 years of light for three hours a day. So they can be installed, connected and then forgotten – because no matter how intensively they are used, it will be a long time before any maintenance work is required.

LEDs burn fifty times longer than incandescent lamps. And are far more efficient than many conventional light sources: their luminous efficacy is much higher and their directional light can be easily and efficiently bundled. An 8W LED lamp, for example, delivers the same amount of light as a 60W incandescent lamp. Today, LED systems can even stand comparison with fluorescent lamps. And their potential is far from exhausted yet: LED luminous efficacy in the past has doubled about every two years.

**LEDs for a "green future"**

Even today, the longevity, efficiency and high lighting quality of LEDs literally make conventional lamps look old by comparison. The days of "energy-guzzling" light sources like the incandescent lamp – generating

[03] The city at night: highly focused LED light is ideal for highlighting architectural details.

[04] Innovative LED technology enhances the gastronomic experience. Discreet spots provide glare-free light at the table.

[05] Street lighting is an area with high potential for savings. Local authorities could reduce their energy consumption by as much as 70 percent. With LED luminaires, it is even possible to achieve a saving of 80 percent. At present, however, LEDs are not yet an optimal alternative for every lighting application.

95 percent heat and just 5 percent light – are finally over.

Climate change, scarce resources and rising energy prices make a re-think essential. And policymakers are acting: The German Energy Saving Ordinance (EnEV) 2009 and the EU Eco-Design Directive for Energy-related Products effective as of November 2009 – transposed into German law as the Energy Using Products Act (EBPG) – set the direction; inefficient products are being removed from the market. The old Edison lamp is one of the light sources set to be phased out across the European Union; the list also includes a number of inefficient halogen lamps, fluorescent lamps and high-pressure mercury lamps.

The solution for the future is LED. Even today, experts estimate that up to 30 percent of global energy consumption for lighting could be saved through the use of LEDs. And that is a great deal of energy – because no less than a fifth of the electricity generated in the world is used for artificial lighting.

The German government is also focusing on the tiny diodes as a source of sustainable solutions. It has sponsored many LED research projects in recent years under the banner of Germany's "High-Tech Strategy". Now, its sights are set on harnessing the wealth of expertise in the German lighting industry to translate LED solutions swiftly into practical products. At the beginning of 2009, the Federal Ministry of Education and Research teamed up with partners in industry and science to launch the "LED Lead Market Initiative". Its purpose is to accelerate the introduction of LED technology on a broad front.

[06] LEDs are the light source of the future. The table below shows the lighting industry's ten-year forecast for lamps and their applications.

## LEDs in lighting today and in the future






| | City/street | Office | Shop | Hotel/Home | Museum | Emergency Lighting |
|---|---|---|---|---|---|---|
| **LEDs** | | | | | | |
| Today/2010 | ● ● | ● | ● | ● | ● ● | ● ● |
| In 3 years | ● ● ● | ● ● ● | ● ● ● | ● ● ● | ● ● ● | ● ● ● ● |
| In 10 years | ● ● ● ● | ● ● ● ● | ● ● ● ● | ● ● ● ● | ● ● ● ● | ● ● ● ● |
| **Fluorescent lamps** | | | | | | |
| Today/2010 | ● | ● ● ● ● | ● ● | ● ● | ● ● | ● ● |
| In 3 years | ● | ● ● ● | ● ● | ● ● | ● ● | ● |
| In 10 years | | ● ● | ● ● | ● ● | ● ● | |
| **High-pressure sodium vapour lamps** | | | | | | |
| Today/2010 | ● ● ● ● | | ● ● | | | |
| In 3 years | ● ● | | ● ● | | | |
| In 10 years | ● | | ● | | | |
| **High-intensity discharge lamps** | | | | | | |
| Today/2010 | ● ● ● | | ● ● | | ● | ● ● |
| In 3 years | ● | | ● ● | | ● | |
| In 10 Jahren | | | ● | | ● | |
| **Halogen lamps** | | | | | | |
| Today/2010 | | ● | ● ● | ● ● ● ● | ● ● ● | |
| In 3 years | | | ● | ● ● | ● ● | |
| In 10 years | | | | ● | ● | |

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**Solutions tailored to needs and good for the environment**

LEDs are highly efficient light sources. But they offer even greater savings potential when used in combination with “intelligent” lighting management systems designed for daylight- and presence-dependent regulation. The dynamic duo achieves savings of up to 80 percent in offices, shops and street lighting – with a corresponding reduction of carbon emissions.

But LED solutions are more than just easy on the environment and the pocket. No other light source has ever offered so much scope for design in terms of form and colour. LEDs can be integrated practically anywhere. Their rich colours add an emotional dimension and offer maximum lighting quality for human needs: LED lighting concepts allow light to be optimally tailored to meet human biological requirements – from cool bright light for concentration to a soothing lighting atmosphere that facilitates relaxation in the evening.

So LEDs are not just an increasingly popular option for accent and event lighting; they are also advancing on the general lighting front. But for LED systems to play out their many advantages, the quality needs to be right. The development and manufacture of efficient LEDs require a great deal of expertise – something which does not go into every product found on the market. Consumers are well advised to rely on the experience of reputable manufacturers.

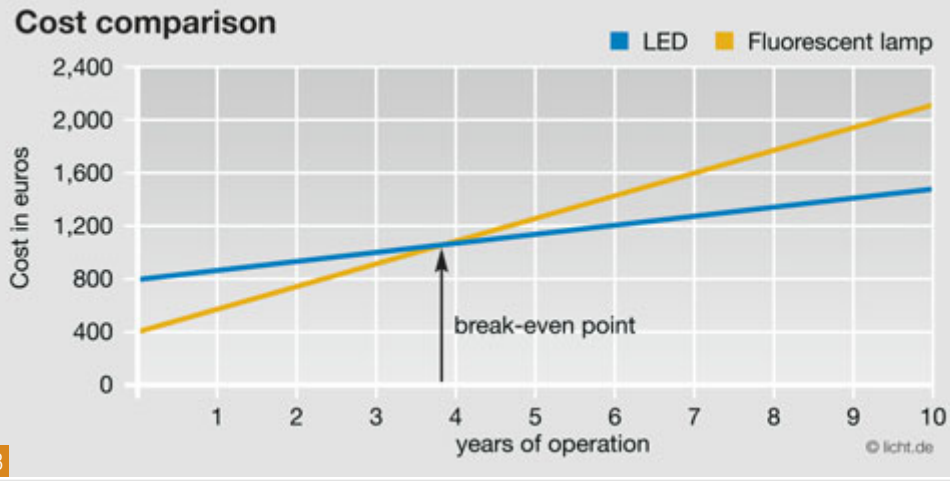
Even today, the cost of a quality system is quickly recouped through high efficiency, longevity and convincing lighting quality. And system performance is improving fast. LED development is advancing just as rapidly as computer and flat-screen technology.

07

## High performers: LEDs in corridor lighting

High lighting quality and efficient technology are compelling arguments in favour of LED solutions for general lighting. As the example here shows, higher capital outlay is quickly recouped. The comparison is based on downlights in a 20 metre long corridor, fitted with 2x26W fluorescent lamps in one case and 26W LEDs in the other. The calculation is based on 10 years of operation with a burning time of 12 hours a day, 250 days a year, and an electricity price of 21 ct/kWh.

| | LED | Fluorescent lamp |
|---|---|---|
| Downlights installed | 4 | 4 |
| Total price of luminaires | 800.– € | 400.– € |
| Total wattage | 104 W | 244 W |
| Maintenance costs | – | 200.– € |

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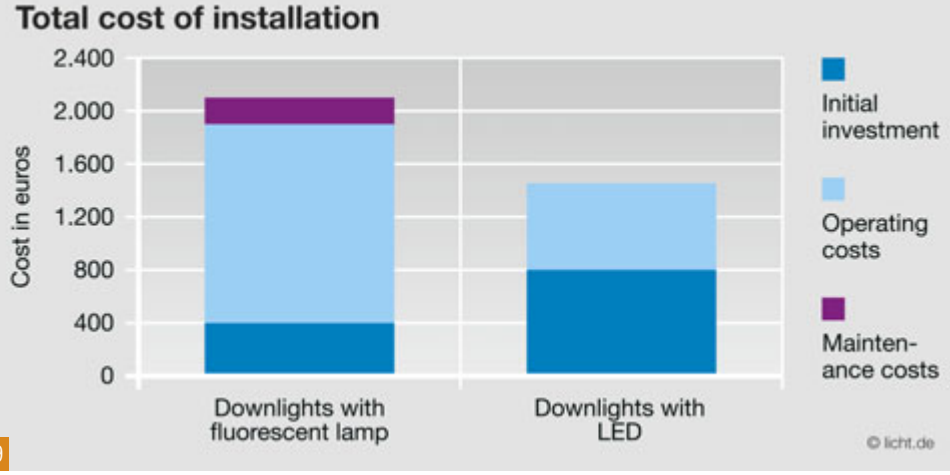


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# LEDs for City and Street

LEDs have been used in decorative outdoor lighting for years. With white light, they now also make for optimal visual conditions on roads and paths. No other lighting technology couples so much freedom for lighting design with such low energy and maintenance requirements.

[10] Ground-breaking: flat recessed spots and a narrow recessed ground luminaire with blue LED light guide visitors safely to the building.

[11] The light of the recessed ground luminaires with LEDs sets distinctive accents in the pedestrian precinct.

[12] The LED luminaires cast agreeably white light evenly over footpath and road. The power required for each light point is just 34W and the LED modules can simply be replaced as required.

Germany's lawmakers have given local authorities a new responsibility; they want them to set a good example in terms of energy conservation. At the same time, the idea is to sharpen city profiles in global competition. Lighting and the face of the city at night play a significant role in this. They heighten appeal, shape image, provide security – and offer massive potential for savings. The German Electrical and Electronic Manufacturers' Association (ZVEI) estimates that a switch to efficient solutions could save around € 400 million a year in street lighting alone.

After all, more than a third of street lighting is over 30 years old. Obsolete technology is responsible for low coefficients of utilisation: inefficient lamps such as high-pressure mercury vapour lamps – which will be banned in the EU in 2015 – consume too much energy. LED luminaires are not just more efficient; they also have other winning features:
> homogeneous light
> long life and low maintenance
> precise optical control, preventing undesirable stray light
> simple dimming and lighting management.

**Tailored white light**

White light is now available in just about any hue required and can be selected to suit the type of street in question: warm white light with a colour temperature in the 2,700–3,000 kelvin range is right for the atmosphere of a historical town centre, park or residential area; LED luminaires producing neutral white light are appropriate for busy roads and business parks – and very efficient at 70 lumen/watt.

Many municipalities are already switching to LED luminaires. In the Lower Saxon town of Soltau, for example, old twin-lamp mushroom luminaires fitted with 80W high-pressure mercury vapour lamps were replaced by LED street lights with single 59W LED modules. The result: the LED solution reduces the energy required by 60 percent. This is due not just to its higher efficiency but also to integrated lenses permitting precise light control even without secondary optics.

10

**Light that meets needs**

Electronic regulators integrated in the luminaires themselves make for very high efficiency: they ensure that light output is automatically kept constant throughout the LED luminaire's life of around 50,000 hours and that illuminance never falls below the minimum level required. These regulators alone cut energy requirements and costs by 15 percent.

Lighting control also enables LEDs to be automatically dimmed in the event that no or only little light is required. When the sensors register the presence of pedestrians, cyclists or automobiles, the lighting can be specifically powered up again to illuminate a particular street section. LED systems can easily be incorporated in lighting or telemanagement systems. Modular concepts facilitate system maintenance and make it easier to replace LED modules at the end of their service life.

Even though it may be tempting, switching from old luminaires to LED solutions or replacing defective lamps with LED retrofit systems is still problematical. Lighting and electrical values need to be checked and approved by manufacturers and operators.

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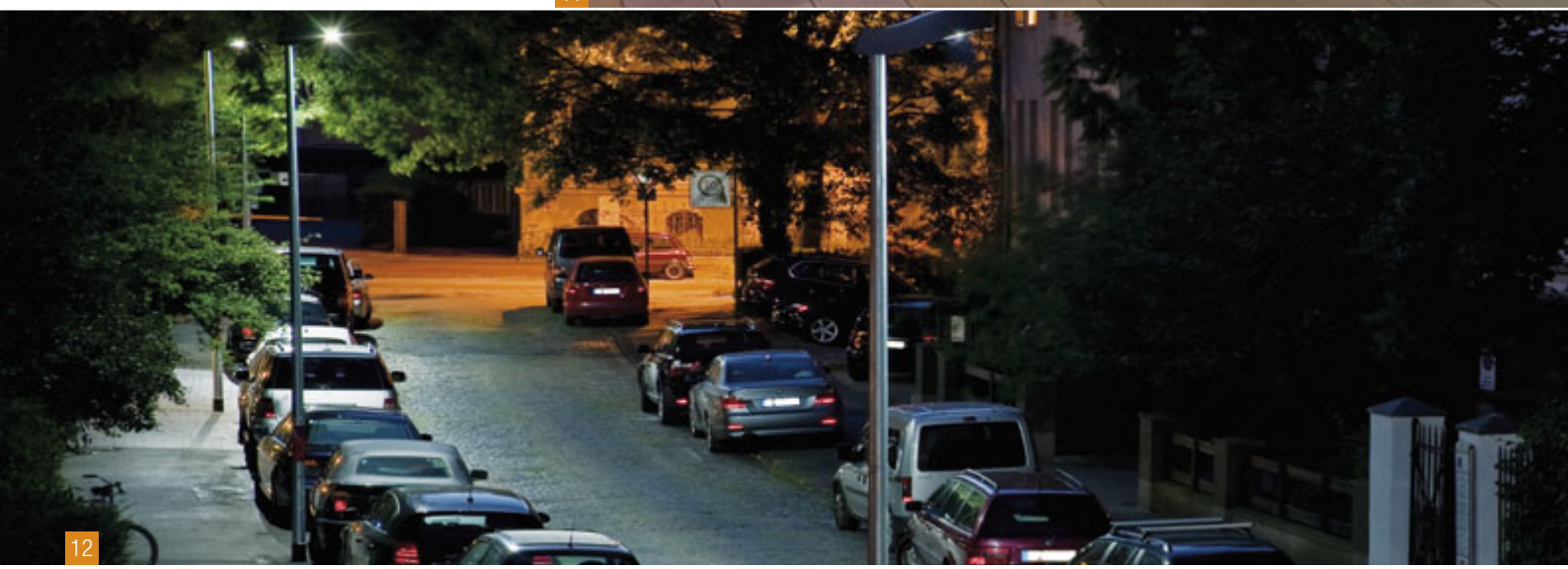

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ATLANTIC

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STADION CENTER
XANAKA
MISTER*LADY
MILLENNIUM TRAVEL
3 Stunden

15



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# LEDs for Facades

From discreet integrated light strip to large-scale illumination, white or coloured LED light heightens the visual impact of architecture and grabs attention.

Their light seems to come from nowhere yet has a remarkable presence: in compact designs and with RGB colour controllers, LEDs provide striking accents on any scale.

They also offer huge scope for lighting design: narrow LED strip winds around bends and corners, lends emphasis to window reveals and arches. Up- and downlights flood facades with homogeneous glancing light that picks out structures in sharp relief. Powerful floodlights with over a hundred high-performance LEDs effortlessly cast light to the tops of spires 240 metres above the ground. And extremely precise lighting effects are achieved by minimalist spots with extremely sharp contours.

LED systems combine scope for design with high efficiency and a long service life. Today, the large-scale floodlighting that was popular in the past is also being increasingly replaced by low-key lighting accents realised by LEDs positioned directly on or close to the facade. This saves even more energy and reduces unwanted light emissions that might disturb local residents.

**Light advertising and “talking walls”**

Intense colours and robust design long ago won LEDs a place in light advertising and corporate colour branding. Flexible, compact LED modules can easily be deployed to illuminate individual characters or entire logos – whether they are three metres high or just a few centimetres. Thanks to their low design height, LEDs integrate harmoniously into the architecture and are a recommended solution for backlighting translucent surfaces.

With the necessary controllers, LEDs create “talking walls”. Media facades are in vogue; they permit moving images at the push of a button and attract lots of attention. Advertising messages, news, light art or even video recordings of events can thus be projected onto facades and walls.

In contrast to fluorescent lamps, special LED modules make maintained, ignition-problem-free operation possible down to temperatures of minus 20° C – without compromising on constant light, brilliant colour saturation and low power consumption. Another advantage: the longevity of LEDs eliminates the need for regular lamp replacement and expensive maintenance work, especially at height, where luminaires are difficult to reach.

[13] High-impact facade lighting: Narrow LED light strip is used here as an indirect light source to accentuate the sheet aluminium facade.

[14] The lettering and the globe on the roof of Hamburg’s Atlantic Hotel are visible from a great distance. The colour of the LED light can easily be varied as required. The light-emitting diode’s long life saves energy and expensive maintenance work in places where access is difficult.

[15] An attention-grabber: The multimedia facade of Vienna’s Stadion Center shopping mall can be used to display static or moving images. The entire facade is enveloped in a flexible, 80-metre long LED net offering attractive possibilities for outdoor advertising. Each of the 37,620 LEDs is individually controlled by a video management system.

[16] LED spots with a highly focused beam direct the eye to historical details.

# LEDs for Office and Administration

Good workplace lighting motivates, promotes health and boosts performance. Intelligent LED solutions meet these high requirements, fulfil statutory energy-saving regulations and make for a sustainable reduction of costs.

A uniform lighting level of 500 lux throughout the office? Those days are gone. Lighting concepts today are no longer static but flexibly adaptable to personal needs: they ensure balanced, tailored lighting at each workplace, they adjust to suit the time of day and they send the right signals to the human biological clock. This promotes a sense of wellbeing in employees and enhances their peformance.

LED systems not only achieve a better quality of lighting. Their high efficiency and long life also make them a long term "green" solution. And scope for improvement in that respect is still present in abundance in small and large offices: anyone who refurbishes inefficient old installations and switches to innovative technology with lighting management can save up to 75 percent of the cost of electricity required for lighting. And since lighting accounts for nearly 40 percent of all the electricity costs in an office building today, the initial investment is generally recouped within just a few years through lower energy consumption.

**LEDs at the workplace**

Workplace lighting needs to meet high ergonomic and economic requirements. Quality office luminaires offer glare-free lighting for optimal visual comfort even at computer workstations. They conform to the relevant standards and are energy efficient.

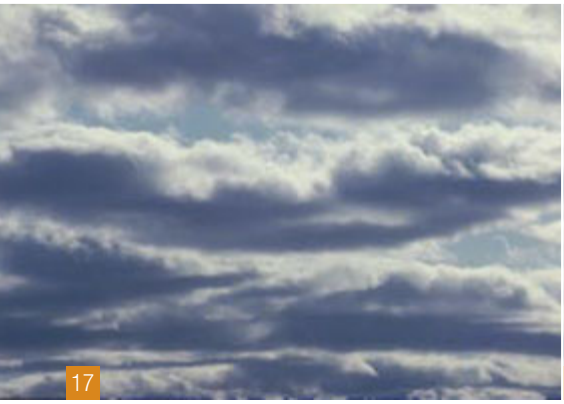
New hybrid luminaires offer the best of both worlds in one system: they combine advanced LED technology, for example, with energy-efficient T5 fluorescent lamps (16 mm lamp diameter) – a mix that makes for extremely efficient direct/indirect luminaires. They ensure that the punctual light of the LEDs is focused and directed onto the work surface while the light of the fluorescent lamps radiates widely and evenly over the ceiling.

Hybrid luminaires thus offer cool direct LED light for optimal colour rendering – and with a high blue content for biological stimulation – as well as warm indirect light for a sense of harmony. The possibility to switch and dim the LEDs and fluorescent lamps separately makes for tailored lighting comfort. A wide variety of lighting atmospheres can thus be created – finely tuned to suit personal preferences and the nature of the work tasks performed. The combination also ensures excellent quality of lighting in conference rooms.

Apart from hybrid luminaires, there are also pendant, recessed and standalone lumi-

[17–21] Lighting atmosphere based on requirements and time of day: the hybrid luminaire for the conference room combines direct LED light with energy-efficient T5 fluorescent lamps for indirect lighting. Separate switching and dimming for the two light sources offers high lighting comfort.

[19] Recessed LED modules make for a friendly reception in the lobby.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naires on the market that work exclusively with LEDs. And companies are starting to switch over entirely to diode technology, using high-performance LEDs to provide all the lighting required for workplaces and meeting rooms, foyers and corridors. Employees' and visitors' footsteps are guided by extremely flat modules that fit seamlessly into the architecture. At workplaces, standalone or pendant luminaires with both direct and indirect lighting components deliver the glare-free 500 lux required.

**Better lighting, lower costs**

The use of innovative LED solutions raises lighting quality while at the same time permitting a sustainable reduction of lighting costs. Savings potential is maximised by "intelligent" luminaire management, whereby the brightness of each luminaire is adjusted automatically in response to presence and daylight sensors. So the artificial lighting provided is no more than is actually needed. This is not only a practical solution for offices. The combination of LED luminaires and lighting management also saves a great deal of lighting energy – and thus costs – in corridors, seminar rooms, toilet facilities and technical rooms.

LED luminaires producing coloured or colour-changing light set striking accents in reception areas, corridors and stairwells. Colour and dynamism emphasize areas with a prestigious character and also enliven meetings. With a wide spectrum of colour temperatures, LEDs can even recreate the natural progression of daylight indoors and thus promote relaxation and activation in line with biological rhythms. And maintenance? With LED solutions, that is not an issue for many, many years.

[22] LEDs provide all the lighting required for this modern office building in Hamburg's Hafencity. General and accent lighting on six floors is delivered by a total of 3,000 LED luminaires.

[23] High intensity and high efficiency: LED ceiling luminaires with acrylic glass diffusor for the aisle zone. The recessed luminaires are only a few millimetres high and radiate light downwards in a wide uniform beam.

[24] At the workplace, standalone luminaires with direct and indirect lighting components guarantee glare-free, standard-compliant lighting. Integrated presence- and daylight-dependent control makes for maximum efficiency.

[25] LED downlights lead the way to the lift.

[26] The suspended hybrid luminaires each feature twelve 3W LED modules and two 54W T16 fluorescent lamps. Their reduced design harmonizes perfectly with the office furnishings.


25


26

# LED Special: The LED Light Source

The advent of the LED brings a totally new light fitting onto the market. In contrast to conventional lamps, LEDs are electrical components – tiny electronic chips of semiconductor crystals.

LEDs produce light – but that is about the only thing they have in common with halogen or energy-saving lamps. Unlike conventional lamps that work by heating a filament or by gas discharge, LEDs are tiny electronic chips of special semiconductor crystals.

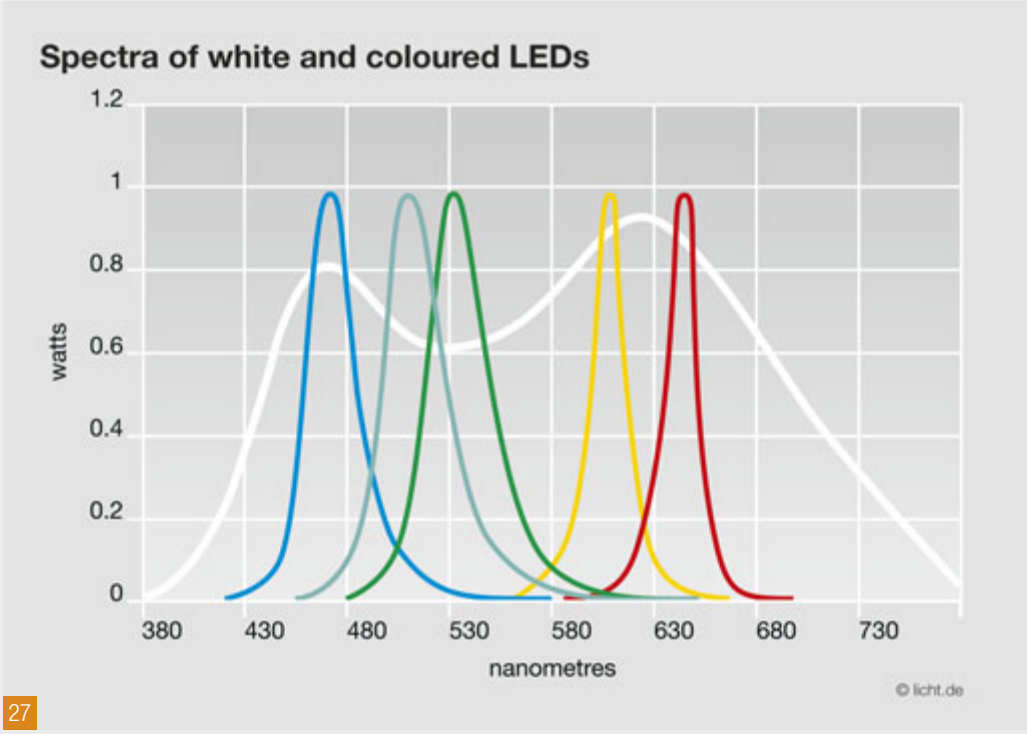
When a current is passed through the solid crystal, it induces electroluminescence: the diode glows, emitting what is sometimes referred to as “cold light”. This is because, unlike the light of an incandescent lamp, LED light is not heat driven.

With edges only around a millimetre long, LEDs are among the smallest light sources available – not much larger than a pencil dot. To protect them from environmental influences, the semiconductor crystals are embedded in a plastic case, which helps produce higher light densities and makes beam spreads of 15 to 180 degrees possible.

Light-emitting diodes always produce narrow-band (=monochromatic) radiation. The dominant wavelength and thus the colour of the light emitted – red, green, yellow or blue – is determined by the semiconductor material used.

**White LEDs and colour rendering**

White LED light can be produced by various manufacturing methods. The method that is most widely used at present is based on the luminescence conversion principle used for fluorescent lamps: a very thin film of yellow phosphor material is applied to a blue LED chip, which changes part of its blue light into white. To achieve the light colour required, the concentration and chemical composition of the phosphor



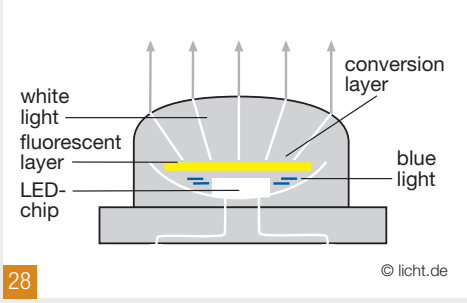

27

[27] LEDs do not require colour filters. The colour tone of the light is determined by the semiconductor material used and the dominant wavelength.

[28] White light is generally produced by luminescence conversion: a very thin layer of yellow phosphor material is applied to a blue LED chip and turns the blue light it emits into white light.

[29] LED luminous efficacy is rising. Values of 200 lumen/watt are already achieved in the laboratory.

material needs to be very precisely controlled. Today, a variety of white tones are possible, from warm white (colour temperature ≥ 2,700 kelvin, K) through neutral white (≥3,300 K) to daylight white (≥5,300 K). Other advantages of this method include relatively high luminous fluxes and good colour rendering up to $R_a \geq 90$.



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White LED light can also be produced by additive colour mixing, i.e. using multi-LEDs or coloured LED modules to mix coloured light of different wavelengths (red, green and blue). This method has the advantage of permitting controlled changes of light colour, allowing not just white but also coloured light to be produced. So RGB solutions are good for dynamic coloured lighting applications. Realising white light by this method also calls for a great deal of expertise because precise control is difficult to achieve with coloured LEDs of different brightness and results in white light with a poorer colour rendering property – $R_a \geq 70$ to 80 – than that produced by luminescence conversion.

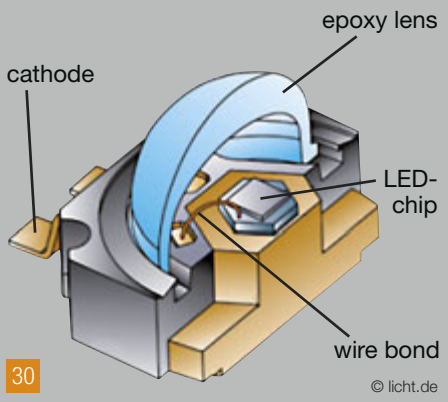
Where white light is required to permit a switch from warm white to cool white for office applications, for example, new technologies combine coloured chips with white LEDs. The result is dynamically changing white light with a good colour rendering property.

### Efficiency and luminous efficacy

LEDs are extremely efficient light sources. The first LED, produced in 1962, achieved a luminous efficacy of 0.1 lumen/watt (lm/W). Today, ratings in the region of 50 l/W are standard and high-power LEDs reach an average of 90 lm/W. By comparison, incandescent lamps achieve around 10 lm/W, halogen lamps around 20 lm/W.

And development continues apace: some LED chips already deliver 200 lm/W. However, such efficiency is achieved only in the laboratory; in practical operation – mounted on a board and integrated in a

## How LEDs work



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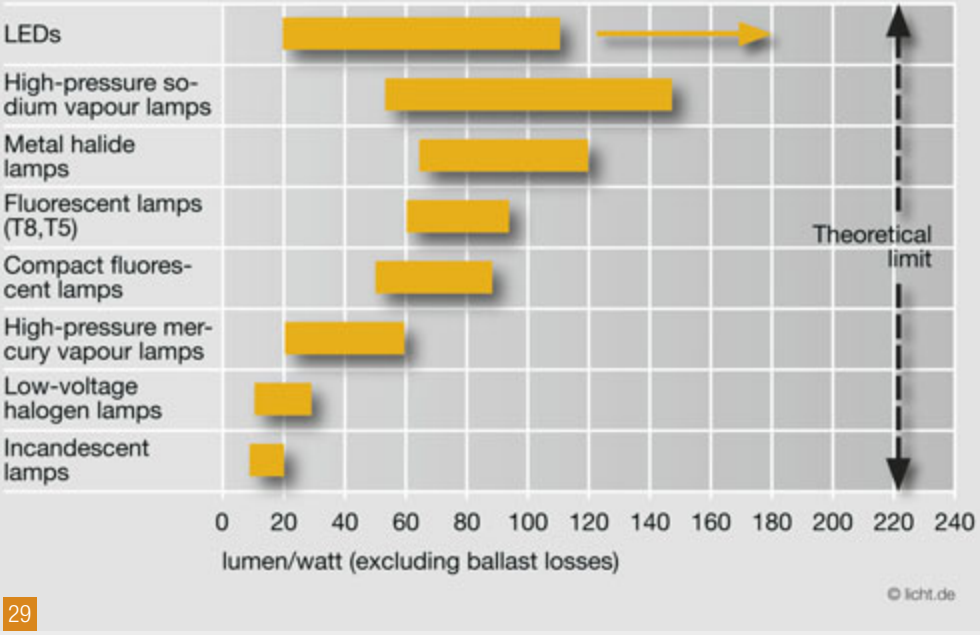
LEDs are based on compound semiconductors. Very little energy is needed to induce them to emit light. Light-emitting diodes consist of a n-type base semiconductor with a surplus of electrons. This is "doped" with a thin layer of p type semiconductor material that has a deficit of electrons, called "holes". When current is applied, the surplus electrons and "holes" migrate towards one another and recombine in what is known as the p-n junction or depletion layer. The energy thus released is converted into radiation in the semiconductor crystal.

To simplify the electrical contacts and protect the LED from environmental influences, it is encased in a housing. Reflectors ensure that the light radiates upwards at angles up to 180°. The light is directed by lenses.

## Efficiency of light sources



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## Colours straight from the semiconductor

LEDs do not require colour filters: their light comes in different colours produced directly by different semiconductor materials. Secondary colours are also possible. The major semiconductors are:

| Semiconductor material | Abbreviation | Colour(s) |
|---|---|---|
| Indium gallium nitride | InGaN | green, blue (white) |
| Aluminium indium gallium phosphide | AlInGaP | red, orange, yellow |
| Aluminium-gallium arsenide | AlGaAs | red |
| Gallium arsenide phosphide | GaASP | red, orange, yellow |

luminaire – the LEDs cannot match that level of performance. LED manufacturers' data sheet specifications are based on ideal laboratory conditions and extrapolations for the raw LED chip. The values do not correspond to the actual luminous flux of an operational LED luminaire or retrofit lamp. What matters in practice is the efficiency of the entire LED system, i.e. the way LED chips, optics and operating devices interact (see also page 57).

**Extremely long life**

LEDs have an extremely long service life. While an incandescent lamp burns for around 1,000 hours and a fluorescent lamp for around 18,000 hours, high-performance LEDs have a life of 50,000 hours or more. This means that an LED luminaire in operation for 11 hours a day, 250 days a year, will last for around 18 years.

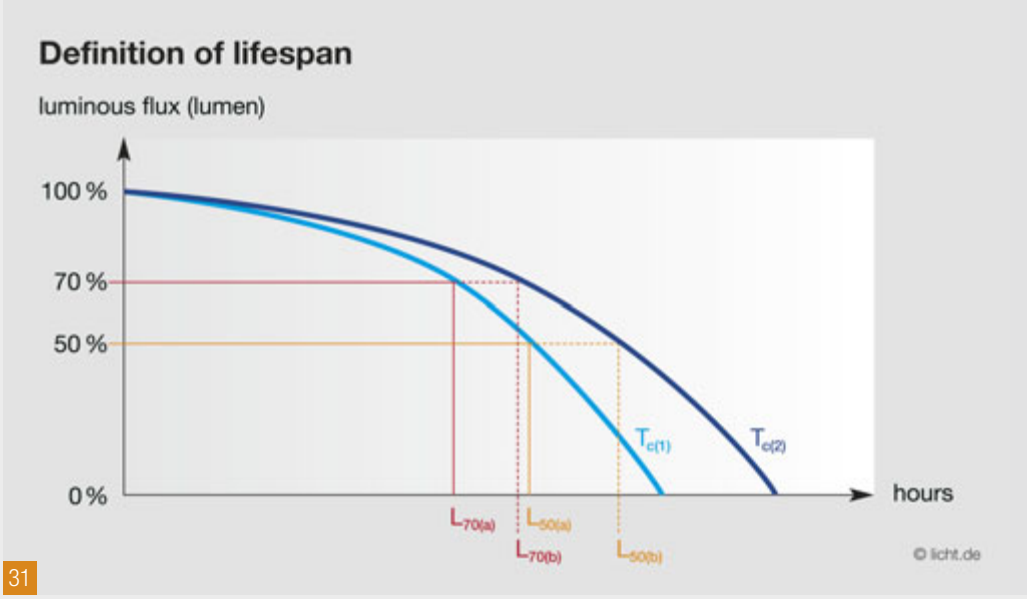
However, the length of an LED's life depends very much on operating and ambient temperature. The colder the location, the more efficiently LEDs work. They do not like high ambient temperatures; their luminous flux diminishes and their life can be significantly shortened. So effective heat dissipation is a particularly important consideration in the development of efficient LED systems.

Unlike conventional lamps, LEDs practically never fail. However, the intensity of their light decreases over time as a result of increasing imperfections in the semiconductor crystal. This characteristic is known as degradation and means that the end of the life of LEDs needs to be defined for a particular application. It is normally reached when the luminous flux emitted by the LEDs decreases to 70 percent (or 50 percent) of the original luminous flux (see Fig. 31).

Because of their longevity, LEDs are virtually maintenance-free in practice. There is no need for lamp replacement or servicing operations.

**Luminous flux and brightness**

Light-emitting diodes have an exponentially increasing current-voltage characteristic, i.e. minor fluctuations in voltage cause major changes in current. So LED chips need to be operated on constant current. They should not be connected directly to a voltage source. The more power a diode consumes, the brighter it shines. The catch is that higher operating currents heat the semiconductor – and thus reduce efficiency. So high-intensity LEDs need good thermal management to remove the heat from the LED chip. Thanks to larger LED chips and new designs for optimal heat dissipation, modern high-power LEDs (1W – 5W) can be operated on higher currents above 100 milliampere (mA). They emit a

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[31] LEDs do not fail but the intensity of the light they produce diminishes over time. The lifespan (L) of an LED thus needs to be defined for different applications. For emergency lighting, for example, ratings up to L80 or more are required; this means that the LED reaches the end of its service life when the luminous flux falls to 80 percent of the original flux measured. For general lighting, values of L50 or L70 are defined. The lifespan of an LED depends to a large extent on ambient and operating temperature. Where an LED is operated at a high temperature (Tc1) or with poor thermal management, its life is shortened.

[32] Highly flexible LED module in SMD technology.

great deal more light than earlier versions and are already breaking records in terms of luminous efficacy: up to 200 lumen on 1A operating current. Simple standard LEDs, by comparison, deliver 1-2 lumen from 20 mA.

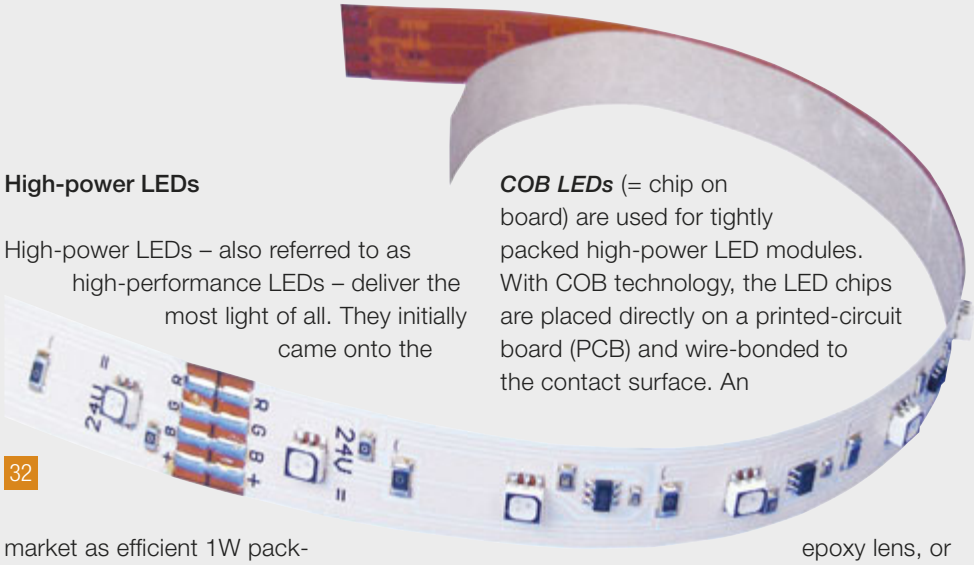
**Low-power LEDs**

Low-power LEDs – also referred to as radial LEDs – include the classical 3 or 5 mm designs, usually with two "legs" and a narrow beam spread of 15° to 30°. The 5 mm LED launched the triumphant career of the light-emitting diode; today, high-performance diodes are in much more widespread use. Low power LEDs operate on currents from 20 mA to a maximum of 100 mA.

Superflux or high flux LEDs (also called spider or piranha LEDs) have four pins. They generally operate on 70 mA and have a higher light output. The housing of these LEDs can also accommodate several chips, which can be separately controlled. Their design permits a wider beam spread of 90° to 130°. Superflux LEDs are used mostly in automotive engineering.

**High-power LEDs**

High-power LEDs – also referred to as high-performance LEDs – deliver the most light of all. They initially came onto the market as efficient 1W packages operated at 350 mA. Shortly afterwards, 3W and 5W high-power LEDs appeared on the scene. At the same time, LEDs were further miniaturised. The smallest high-power LED available is little larger than a matchstick head and achieves 100 lumen/watt efficiency.

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**Types of LED**

***Wired LEDs*** (radial LEDs) date back to the early days of LED technology. The internal LED chip is encased in a plastic housing that protects it from damage. Today, because of their generally low light output, these low-power LEDs are predominantly used for simple signal indicators.

***COB LEDs*** (= chip on board) are used for tightly packed high-power LED modules. With COB technology, the LED chips are placed directly on a printed-circuit board (PCB) and wire-bonded to the contact surface. An epoxy lens, or "bubble", defines the beam spread, which can be narrow or wide-angled.

***SMD LEDs*** (= surface mounted devices) are very small mass-produced products. They are placed directly on a PCB and electrically contacted by soldering. Like wired LEDs, they are encapsulated. SMD LEDs are the type most widely used in modules or luminaires.

SMD models are fitted both with low-power LEDs and with high-power LEDs. They permit the industrial production of high-performance modules of extremely shallow and narrow construction.

## History of the LED: A long road to market

1907 … English experimenter Henry Joseph Round discovers that inorganic substances can emit light when an electric current is passed through them. He reports his findings the very same year in the journal "Electrical World". However, because his primary focus is the development of a new radiolocation process for shipping, his discovery initially sinks into oblivion.
1921 … The Russian physicist Oleg Vladimirovich Losev observes electroluminescence again. Because he believes it to be the converse of Einstein's photoelectric effect, he studies the phenomenon more closely through to 1942.
1935 … George Destriau reports on light produced by passing an electric current through zinc sulphide powders and calls it "Losev light" in honour of the Russian physicist.
1951 … The development of the transistor brings a scientific breakthrough for semiconductor physics. The emission of light can now also be explained. At first, scientists keep on experimenting with zinc sulphide. It is not until 1959 that light generation research focuses on semiconductors; particularly important here is the visible light emission produced by a mixed crystal of gallium arsenide (GaAs) and gallium phosphide (GaP).
1962 … The first red luminescent diode (GaAsP) appears on the market, developed by the American scientist Nick Holonyak. It marks the birth of industrially manufactured LEDs.
1971 … Owing to the development of new improved semiconductor materials, light-emitting diodes are now also available in other colours: green, orange, yellow. At the same time, steady progress is made on improving LED performance and efficiency.
1980s through to the early 1990s … The new semiconductor material gallium nitride (GaN) permits green tones through to ultraviolet and paves the way, in 1993, for Shuji Nakamura's invention of the first commercially successful brilliant blue LED in Japan. Blue LEDs prior to that were based on the indirect semiconductor silicon carbide, which is not very efficient. As well as the blue GaN LED, Nakamura develops the very efficient green indium gallium nitride diode (InGaN-LED) and later also a white LED.
1995 … The first LED using phosphor material to produce white light by luminescence conversion is presented. Two years later, these white light-emitting diodes are on the market.
2006 … The first 100 lm/W LEDs are available. In terms of efficiency, they are surpassed only by gas discharge lamps.

In the recent past, the efficiency of LEDs has doubled every two years. They are conquering more and more applications and their development shows no signs of coming to a halt …

# LED Special: Modules, Systems – and Quality Features

Light-emitting diodes can only be used for lighting tasks when assembled as a module on a printed circuit board (PCB). The production of high-performance modules, lamps and complete LED luminaires calls for special manufacturing processes and a great deal of technological expertise is needed to meet the relevant quality requirements.

[33] LEDs are generally used as modules, which are either custom-designed or standardised. These modules offer optimal scope for fine-tuning to the relevant application and can be used directly as encapsulated modules even without a luminaire housing. The two LED retrofit lamps on the right replace incandescent lamps with a screw base (top) and halogen reflector lamps with a pin base (bottom).

The tiny semiconductor diode has presented a new light source for lighting: the LED module. Basically, it consists of one or more light-emitting diodes mounted on a PCB. The PCB provides the electrical connection for the diodes, dissipates heat and enables the LEDs to be controlled. The flat modules permit flexible and efficient use of LED technology. They are fitted with different types of LED, depending on application.

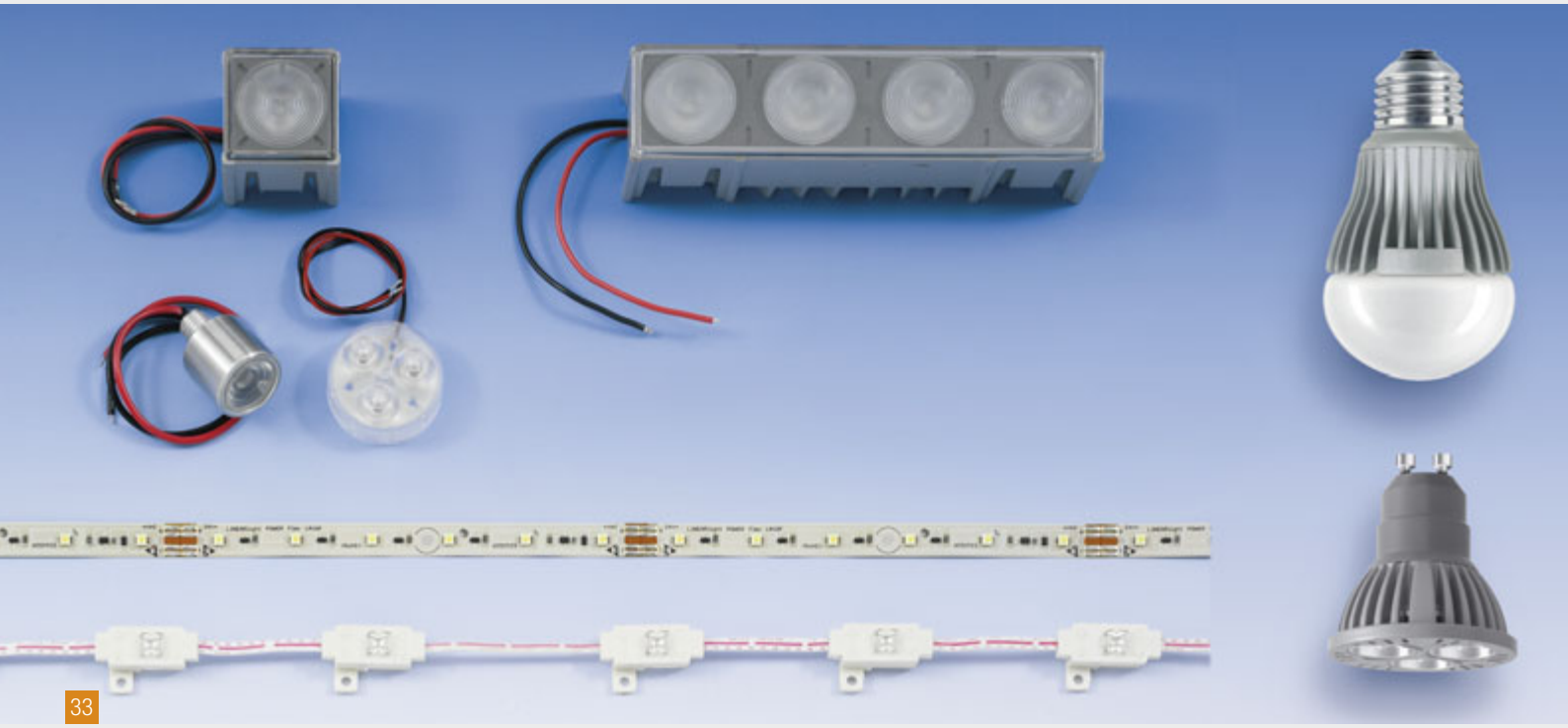
**LED modules**

LED modules are a versatile light source permitting totally new design solutions. As encapsulated modules, they require no housing and can be directly recessed, for instance, in floor or ceiling ducts. As individual modules, they are integrated in minimalist LED luminaires and, with an appropriate base, serve as replacements for many conventional lamps.

***Linear LED modules*** are particularly suitable for wallwashing effects and for architectural lighting. They give depth to facades and arches and fit into narrow outlet ducting. They can also be used to realise long lines of light.

***Flexible LED modules*** are particularly good at negotiating curves and corners. They are mostly fitted with SMD LEDs. The flat modules are the right solution where curved surfaces need to be illuminated or back-lit, e.g. lettering or handrails.

***Planar LED modules*** are normally available as ready-to-use LED panels with diffuse glass or plastic surfaces. They are used as light tiles or complete luminous ceilings.



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Where a number of modules are connected – and an appropriate control system installed – large-area displays can be realised.

***LED chains*** are used where surfaces need to be back-lit or under-lit, e.g. in light advertising.

**Retrofit lamps: LEDs with base**

LEDs with pin or screw base are a special module variant. With an E14 or E27 screw base and a classical "bulb" design, they replace conventional incandescent lamps; with pin bases, they replace the corresponding halogen lamps. Delivering warm white or coloured light, retrofit LED lamps are an energy-saving alternative for home or small office use. They can simply be inserted into existing luminaires. However, they do not match the performance of a complete LED luminaire. Even so, they are a good alternative: an 8W warm white LED light bulb, for example, has a life of around 25,000 operating hours – which is nearly 25 years at almost three hours a day.

**LED luminaires and LED systems**

One of the prime requirements for an efficient LED solution is optimal synchronization of module and luminaire housing; the two always form a complete system. Their production calls not only for a great deal of development and manufacturing expertise but also for the use of high-grade materials. Among the distinguishing features of a quality luminaire are good – and compact – solutions for lighting control, thermal management and optical design.

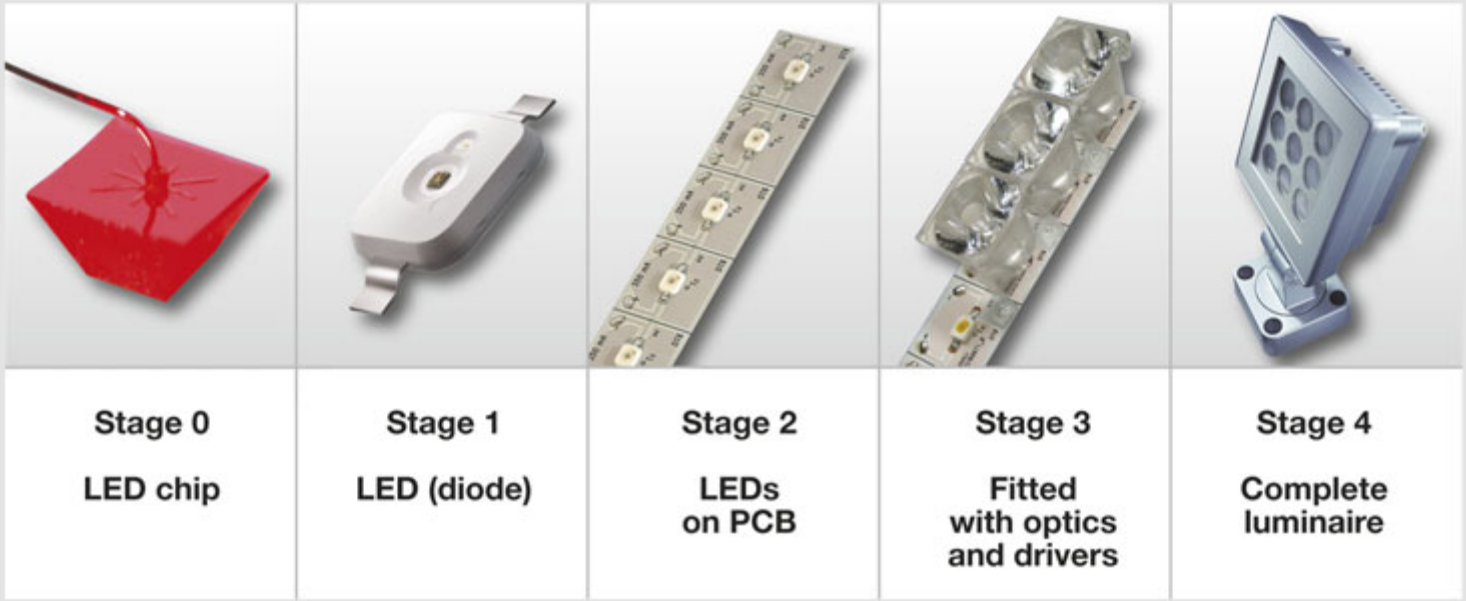
LED luminaires or LED systems for recessed and surface-mounted fittings are always made in four stages (see Fig. 34): Their manufacture starts with an LED chip, which is encased in plastic to protect it from environmental influences and define its emittance characteristics and then placed in a housing.

This diode (stage 2) is mounted on a PCB, which provides the electronics, control and thermal management. In the third stage, the LED-PCB is then fitted with secondary optics such as lenses, reflectors or diffusers.

In stage 4, the LED module is integrated in the LED luminaire. In this production phase, a great deal of attention is paid to the rear of the luminaire, where thermal management is a major issue. This ensures

[34] The production of efficient LED systems calls for a great deal of technological expertise. The quality of the components and the standard of manufacturing are crucial for the efficiency and performance of an LED luminaire.

**LED luminaire production**

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that heat is conducted away from the diode and is crucial for the efficiency and lifespan of the system as a whole.

**Quality features and maintenance factor**

LEDs are in vogue – and the market is flooded with products that do not always meet the necessary requirements. In many cases, poor systems do not reveal their weakness until they are in operation. Quality products
> offer balanced luminance that cannot harm the human eye,
> have minimal early failures (approx. two per million LEDs) and carry a manufacturer's warranty,
> offer the prospect of future replacement in the same lighting quality despite the rapid development of LED technology,
> feature good thermal management, ensuring that luminaires do not get too hot and can be touched without risk,
> offer a good maintenance factor.

The maintenance factor (MF) of a lighting installation is the ratio of the luminous flux at the time of maintenance to the original luminous flux when the system is installed. It takes account of
> the reduction of luminous flux due to the failure and ageing of lamps,
> the possible soiling of a luminaire in the course of time,
> room or outdoor conditions that may contribute to soiling and ageing.

For example: Where MF = 0.5, a lighting installation needs to produce twice as much luminous flux at the outset so that it will still provide the illuminance required for standard compliance by the end of the first maintenance interval. Generally speaking, the quality of LED luminaires is reflected in uniform light colours and homogeneous brightness as well as in the rated life of the system as a whole. Important issues in this context are thermal management and binning.

[35] Agreeably uniform, glare-free light is provided in the office by the extremely flat suspended task area luminaire with direct/indirect light distribution and integrated lighting management system. Another advantage is its long life, which saves maintenance costs.

35

### Thermal management

Even though the light radiated by an LED is not hot, it is wrong to assume that LEDs do not give off heat. Just like other lamps, LEDs convert only part of the incoming energy into light – the rest generates heat inside the semiconductor. To ensure a long life and high efficiency, it is imperative that this heat should be transferred. This applies particularly to high luminous flux LEDs.

Reliable manufacturers thus always quote an LED ambient temperature in which the luminous flux and lifespan of their luminaires and modules are reached.

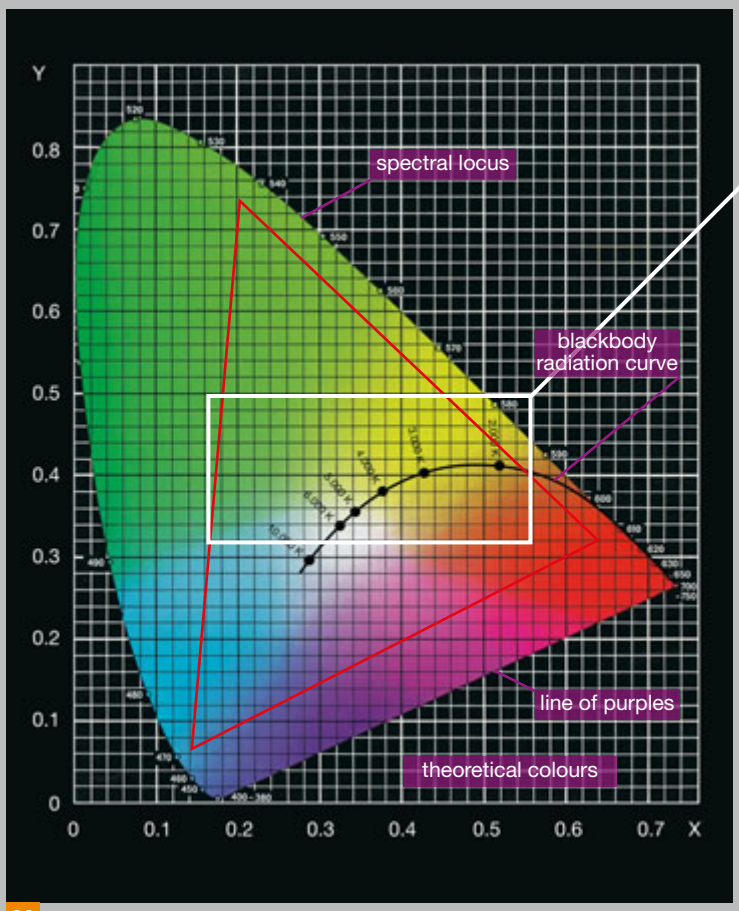
### Binning

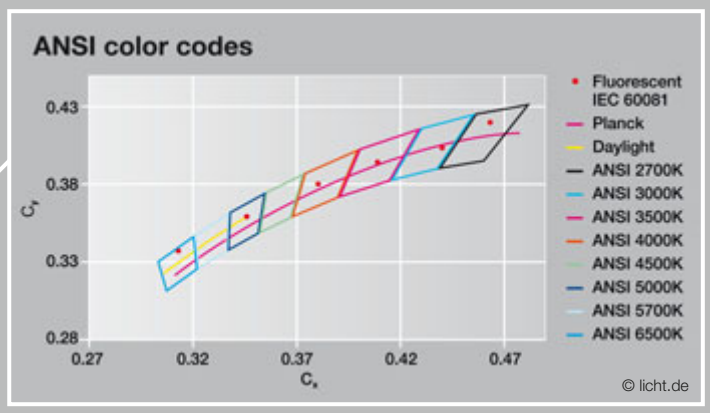
In the industrial production of LEDs, there are always differences within batches: diodes vary, for example, in their colour and luminous intensity. To guarantee constant lighting quality with the same brightness level and uniform light colour, LEDs need to be sorted within each batch. This is called binning. Major selection criteria here are:

> luminous flux, measured in lumens (lm)
> colour temperature, measured in kelvins (K)
> forward voltage, measured in volts (V).

[36] ] Uniform LED light colours are guaranteed by ANSI binning.

## Definition of white LED colours




The colours of LEDs are subject to natural fluctuations. To guarantee a uniform light colour, they need to be categorised. The process of sorting LEDs by colour is known as binning.

The red triangle in the chromaticity diagram (left) of the International Lighting Commission CIE indicates the space in which a chromatic locus could theoretically be plotted by mixing the colours of three LEDs. If the binning group is on the black curve of the Planckian locus, it is classed as “pure white”. If the bin is above the line, the LED has a greenish tint.
Today, LEDs are sorted on the basis of the ANSI bin standard (ANSI = American National Standards Institute). This defines colour variations in xy space with the help of a MacAdam ellipse and recommends that colour values should be within an ellipse with four threshold units. LEDs in these tightly defined bins guarantee uniform light colours, e.g. 2,700 K for warm white.

# LEDs for Hotels and Hospitality

From traditional hotel to trendy bistro, country inn to wellness oasis – successful “hosts” cosset their customers, offering pleasure and wellbeing. The right light is just as important here as impeccable service.

Lighting plays an important role in hotels, restaurants and wellness centres. It contributes crucially to a guest’s sense of wellbeing and desire to return. Here, light plays out its emotional qualities, underlining a comfortable and agreeable atmosphere.

At the same time, lighting facilitates orientation, e.g. on parking decks, in corridors and passageways. In conference rooms, hotel rooms and service areas, lighting also needs to cater for different room uses – while keeping costs as low as possible.

High-power LED systems meet the complex requirements of restaurants and hospitality venues at the highest level: They

> can be flexibly controlled and offer dynamic scene-setting lighting in rich colours,
> provide different white tones to underline a homely or fresh ambience,
> have a service life of 50,000 hours or more,
> are very efficient,
> are small and discreet and accentuate architecture,
> save maintenance costs and have a low environmental impact.

The tiny power packs not only ensure first-rate lighting quality; they are also extremely economical on energy. LED solutions and intelligent lighting control can cut lighting costs by as much as 75 percent. Another

37

advantage: their longevity saves maintenance costs by eliminating the need for frequent lamp replacement in difficult places like high stairwells. What is more, the low heat gain of LEDs reduces air-conditioning costs.

**First impressions count**

With a broad spectrum of colours and colour temperatures, LEDs ensure a friendly reception. They provide guidance for visitors and facilitate communication between guests and staff. Planar light conveys generosity and makes for good general lighting. Such solutions can be realised with flooding LED light from cornices or with a full diffuse opal “skylight ceiling” of back-lit glass. Warm white light or cheerful bright colour tones are the most suitable options.

Walk-over recessed floor lights or discreet light panels in the wall guide the visitor to the reception. There, the glare free warm white light of elegant LED luminaires facilitates work at the computer. Good colour rendering with $R_a \geq 90$ guarantees that colours, faces and objects look natural.

In lobby, bar and corridor, directional LED spots set striking accents as energy-efficient replacements for halogen lamps. Their big advantage: they emit neither ultraviolet nor infrared light. So even old masters sustain no damage and eye-catching creations on the dessert buffet are cast in an appetising light with no risk of them drying out.

**Colour and dynamism for lighting comfort**

Coloured lighting for selected surfaces and dynamic light hold a special fascination. Experienced hoteliers are not the only ones


38

[37] The slate wall is an eye-catcher in the lounge, lent depth by cubic recessed luminaires with single 1.2W LEDs radiating light in three different white tones.

[38] The right lighting helps us unwind. Here, a homogeneous “light wall” provides agreeably diffuse light at the bed.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who realise this; the positive impact on human beings has been confirmed by numerous studies. With LED solutions, it is particularly easy to harness the beneficial effects of colour and dynamic light. And there is no need for colour filters: given an appropriate module, a single LED luminaire can produce more than 16 million different colours as well as a range of white tones.

LED lighting with dynamic colour management has various uses. In a hotel room, it enables the guest to set “his” lighting to suit his biorhythms – fresh white tones with a high blue content in the morning to help him wake up, more red content in the evening to help him unwind. In conference rooms, the lighting can be switched as required from concentration-boosting white tones through gently soothing mood light to inspiring colour changes for creative brainstorming.

Intelligent, sensitive colour management also makes for great effects in wellness centres – effects that customers appreciate. Green tones are soothing for a relaxing massage, a delicate violet is good for the rest zone of the sauna and turquoise blue conveys a sense of cleanliness and freshness in the whirlpool. To ensure safety in swimming pools, plunge pools and showers, however, any LED luminaires used there need to be designed to appropriate degrees of protection.

High-quality LED systems can be infinitely dimmed. They can thus provide subdued lighting for guests in rest zones and bright light for cleaning.

Video-capable LED systems add a highlight to lounge and bar areas. They let ceilings tell stories. Programmed to create different shapes and slowly changing colours, they make for a subtle cosy atmosphere; loaded with images, they set trends. The planar luminaires can be installed on ceilings or walls.

**Lighting management for comfort**

Tailoring lighting to preferences and needs calls for lighting control and appropriate management systems. They should be easy to use and convenient for guests and staff. Simple control is offered by multifunctional operator interfaces where a single panel replaces a cluster of switches and dimmers.

Clearly identified programmed lighting atmospheres can be activated at the push of a button or by remote control – a welcome convenience in any hotel or conference room. At the same time, lighting and blinds can be adjusted to suit daylight and weather. Where time of day and human presence are taken into account, lighting management permits a further sustainable reduction of energy consumption. This also makes good financial sense in toilet facilities and on parking decks.

Long-life low-consumption LED luminaires combined with lighting management thus meet the requirements for efficient, top-quality lighting for every part of a building. Depending on configuration, all areas can be centrally monitored and controlled – from hotel room to car park.


41

[39] Downlights and cornice lighting over the entrance mark the route to the reception.

[40] LEDs create an attractive lighting atmosphere in the restaurant: the back-lit counter is a prominent design feature. Slimline LED modules also set the scene for glasses on the shelves on the rear wall.

[41] LED solutions with dynamic colour management are a good choice for wellness facilities. They pamper guests with stimulating or relaxing light, depending on the time of day.


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# LEDs for Art and Culture

Modern art, sculpture or old manuscripts: exhibition lighting requires a very sensitive touch and gentle light. With dynamic light, LEDs also introduce colour and movement into the scene.

Any lighting design for a museum or art gallery needs to focus on the exhibits. An attractive dramatic lighting installation takes account of this: while effectively showcasing architecture and exhibitions, the light sources themselves remain discreetly in the background. Because of very compact dimensions and extremely shallow design, this presents no problem for LED modules.

**Luminous ceilings open up rooms**

Especially in modern museums and galleries, there is a marked trend towards the use of large diffuse light panels. The advantage: their soft flooding light blurs the boundaries of the room and softens hard contours. So large back-lit ceilings or panels are ideally suited for general lighting. With long-life LED light tiles, light lines or special module strings, such luminous ceilings can easily be realised for a virtually maintenance-free solution.

The contrast between the diffuse light of an LED light panel and the highly focused directional beam of LED spots holds a particular allure. It focuses attention on the exhibits while at the same time structuring the room and facilitating orientation. With LED spots on power track or gimbal-mounted – i.e. rotatable – downlights, the accent lighting remains flexible for revolving presentations.

**Changing light**

LED solutions coupled with dynamic lighting management provide the full range of RGB colours and a broad spectrum of pastel and mixed colours for individual lighting "productions". With no need for colour filters and at the push of a button, the light changes from stimulating cool blue through warm white to glowing red. The lighting can thus be perfectly tuned to suit different periods in history and different exhibition themes. Bright glossy materials such as photographs, for instance, acquire a special brilliance at high colour temperatures around 5,000 kelvin: historical costumes or furnishings show all their facets at a warm 3,000 kelvin. Additional accents can then be set by adjustments in brightness between 10 and 100 percent.

**LED light is gentle on old masters**

Museum lighting also needs to take account of conservationist requirements. Oil paintings, old documents and fabrics are sensitive and must not be exposed to harmful light or heat. LEDs rise to the challenge with ease: they emit neither ultraviolet (UV) nor infrared (IR) radiation and the light they radiate remains cool. They thus protect sensitive exhibits from degradation and preserve their colours.

**Dramatic effects on stage**

At rock concerts, in the theatre or for TV shows – where attention-grabbing productions are presented, rich colours and changes in lighting are a must. Modern control systems with digital interfaces ensure successful effects. With large numbers of LED points, for example, large panels can not only be activated, deactivated or dimmed; each light point can even be separately controlled to produce changes in colour and intensity. With video-capable LED luminaires, which can play back images and film sequences, light itself becomes the star of the show.

[42] Modern LED spots are perfect for the museum because of their versatility. Colour temperatures and colours can easily be modified to cast the relevant exhibits in exactly the right light. LED light contains no UV or IR radiation, so sensitive materials are protected.

[43] Energy-efficient LED spots on a slender track system illuminate sculptures perfectly from a height of five to six metres.

[44] The old manuscripts in the showcases are gently and evenly illuminated with LED light.

# LEDs for Shops und Presentation

Saturday shopping in the city or at an outlying retail park: flexible LED light makes shopping an emotional experience, helps staff serve customers better and contributes substantially to the success of the business.

[45+46] LED light turns this shop into a place of delight and discovery – and dispenses with visually obtrusive luminaire housings. Gentle flooding light is provided by large light walls, while fine light strips illuminate the showcases.

[47] The eye-catcher of the mall: an LED media ceiling that can be programmed to display moving or static images.

In an exclusive brand outlet or supermarket deli department, modern lighting sets the stage for the merchandise on offer and creates an ever-changing backdrop of exciting environments. Flexible coloured LED light gives the presentation the right pizzazz. It guides and informs, dramatises and differentiates...

Light-emitting diodes have an outstanding track record as more than just sales promoters. Extremely efficient, each one of them helps reduce energy costs for 50,000 working hours – which makes a noticeable difference. Lighting accounts for around 25 percent of the electricity consumed in retailing, so it is well worth paying special attention to it and to intelligent options for managing the energy it consumes.

**LEDs make light move**

Modern LED technology introduces a totally new tone to the exciting dialogue between lighting and merchandise. Particularly trendy at present are luminous ceilings, which gently flood an interior with light. In large malls especially, they make for a positive lighting atmosphere and blur the boundaries of the retail space. Video-capable LED media luminaires can display images and messages on the ceiling at the push of a button – or reproduce the sky over the course of the day. If required, they can also be used to present moving or static images without compromising on image quality or uniformity of colour. Dynamic colour and light management sets the scene for product presentations and window displays. With electronic control systems, any lighting combination and atmosphere can be programmed for activation in the sequence required.

**Coloured light for any collection**

Coloured light is a major issue in retailing: discreetly illuminated coving between walls


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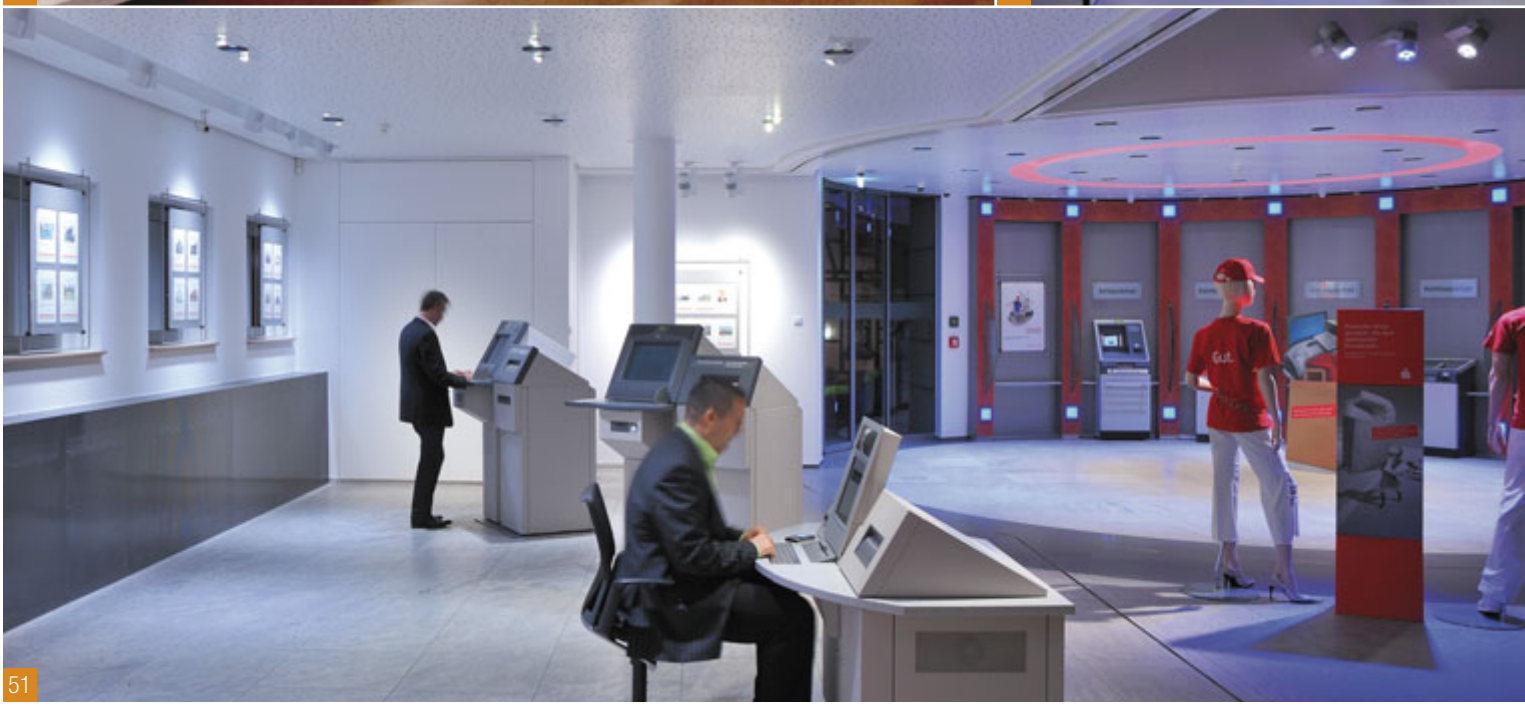
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and ceiling blur boundaries, recessed floor lights identify different zones, directional spots direct the eye to product presentations. With LEDs it is easy to combine agreeable white general light with coloured accents.

For example, lighting can change with each new collection: fresh yellow and green tones for summer, warm orange and reds for autumn and cool white and blue for winter. It also works in a delicatessen department. Cool colours underline the freshness of fruit, meat and fish; spots switching between red and green provide charming lighting for fine wines.

**LED light for sensitive merchandise**

Projected light directed straight at an object produces high luminance. That attracts attention. With LEDs, spotlighting even sensitive merchandise – cosmetics, foodstuffs, sensitive fabrics or leather – is problem-free. The light they emit contains no harmful infrared or ultraviolet rays; supplementary filters are no longer necessary.

As a result, spots and LED luminaires can be installed directly in shelving systems, so the energy needed to illuminate merchandise is less than where conventional accent lighting is used.

**Solution for difficult locations**

The longevity of LEDs saves maintenance, which is particularly welcome where lamp replacement is difficult or expensive, such as on escalators or in rooms with very high ceilings.

LEDs are also good for freezer cabinets, where they can simply be used in place of fluorescent lamps. The big advantage is that whereas fluorescent lamps provide less light at minus 20° Celsius, LEDs literally find a new lease of life at sub-zero temperatures. They are also unaffected by vibrations caused by slammed doors – and they generally enjoy a longer life than the freezer itself.

[48] Elegant lighting solution for the counter: white LED light floods out of the cornice beneath the ceiling, emphasizing the curves of the counter.

[49+50] Coloured light directs attention and can be adapted to suit any collection.

[51] With functional white light and coloured special-effect lighting, the lighting concept for the bank helps create an agreeable atmosphere and conveys a sense of security in the evening. Providing warm to cool white light, variable colour temperature LEDs enable the lighting to give the right prompts for human biological rhythms during the course of the day.

[52] During the day, the shopping mall is flooded with daylight; in the evening, efficient LEDs take over. Coloured light accentuates the architecture.

[53] LEDs are perfectly happy at sub-zero temperatures. Bathing the frozen foods in uniform light, they are economical on energy and vibration-resistant.


52


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# LEDs in Hospital and Surgery

The healthcare system is changing. Hospitals, doctors' surgeries and care facilities are becoming modern healthcare centres and need to be competitive. Tailored lighting concepts help patients feel well looked after.

Even the Ancient Egyptians were aware of the power of colour: they immersed their sickrooms in warm red light. The beneficial effect that colour and dynamic lighting have on human beings is confirmed by modern science. While the focus in the past was on optimal lighting for diagnosis and therapy, the emphasis in hospitals, surgeries and care facilities today is increasingly on making use of the psychological and aesthetic impact of light.

Such concepts can be easily and efficiently realised with LED systems. Colour adds an emotion dimension to light – and impacts directly on a patient's sense of wellbeing. Efficient and flexible LED solutions invite creative use of light – facilitating orientation as recessed wall and floor luminaires, lending structure to long windowless corridors as wallwashers in combination with brilliant accent lights, receiving patients in the recovery room and reassuring parents-to-be in the delivery suite as diffuse luminaires.

**The right "medicine": LED light**

Gentle coloured light is not only the right "medicine" for fear and anxiety in a waiting area. It is also found increasingly useful in places where surroundings are predominantly defined by medical equipment. For CT (computer tomography) scans or digital mammography, an ambience shaped by coloured light significantly helps patients relax. And because less anxiety means less stress, examination error rates are also lowered.

54

[54] Warm colours and warm white LED light help mothers-to-be feel at home at Nuremberg Hospital.

[55+56] Creating a bright and cheerful atmosphere, the lighting concept for the surgery is based entirely on LED luminaires. The simple elegance of the light fittings is a perfect match for the furnishings.

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RGB control enables light to be tailored to any requirements: white or coloured, bright or gently dimmed, static or programmed for dynamic change. So an agreeable lighting atmosphere can also be realised in a patient's room to take account of human biological rhythms: cool daylight white for the doctor's round in the morning, warm white light for relaxation in the afternoon, dimmed general lighting supplemented by accent lighting in the evening.

**LEDs in the doctor's surgery**

Combining high performance with purist design, efficient maintenance-free LEDs also ensure optimal lighting at a doctor's surgery. Diffuse light tiles or recessed spots facilitate orientation, luminaires with direct and indirect components provide glare-free lighting for waiting areas and for places where work is performed at computers and electronic equipment. Spots put pictures, sculptures and plants in the limelight.

In treatment rooms, doctors and nursing staff need good general lighting of around 500 lux and flexible lighting for examinations. With intelligent management systems, lighting can easily be switched and dimmed. This ensures comfort and adds to energy savings.

**Lighting for examinations and surgery**

High-intensity high-power diodes are also increasingly used for examination luminaires. The advantages are not only a long life, which keeps maintenance to a minimum, but also their hemispherical radiance and the ample scope for using optical control elements to direct the beam of the "punctual light sources". Also, in contrast to conventional lamps, LED light contains neither ultraviolet nor infrared radiation, which is good for skin and bodily tissue.

The use of different coloured LEDs in a luminaire facilitates assessment of the condition of skin and wounds. This is basically due to a "shortcoming" – because the colour rendering properties of neutral white LEDs (Ra ≥ 90) at present are often not good enough for the demanding visual tasks performed in an operating theatre. So until diodes with optimised phosphor coatings for a higher colour rendering index are available, neutral white chips are combined with other light colours. This smoothes out the spectral profile of the luminaire and guarantees optimal colour rendering.

Colour mixing also offers physicians the option to vary the white LED light for a particular examination at the push of a button or through use of a remote control device. For example: neutral white for general examinations, warm white light for examining skin, cold white light for vascular identification.

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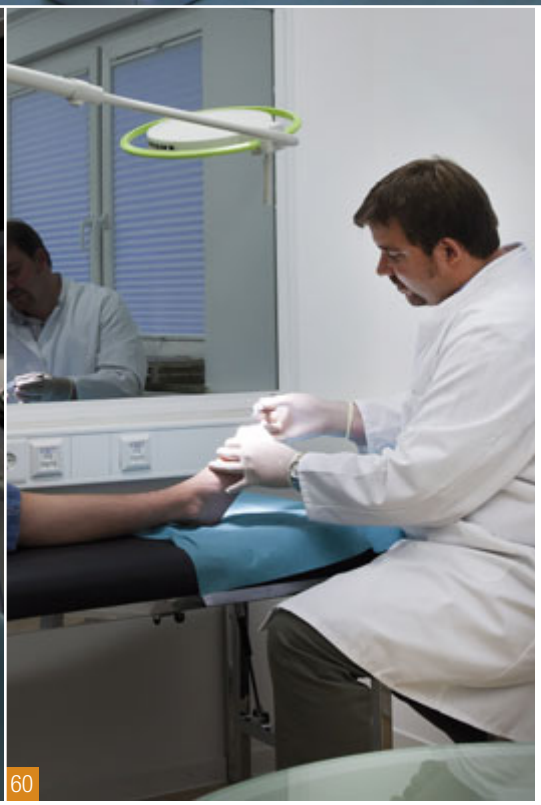

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[57] Art in the surgery corridor. The filigree aluminium wall luminaires are fitted with 8W LEDs, which is equivalent to a 30W halogen lamp. The 2W LED wall luminaires at knee height mark the route through the surgery.

[58] Operating theatre lights with high-intensity LEDs facilitate the demanding visual tasks performed by surgeons. Light colour and brightness can be changed in seconds.

[59] Lighting atmosphere with a twofold effect: dynamic LED lighting helps quell any anxiety that the patient might feel and thus also reduces the risk of false readings. More than 60,000 different light colours can be created in the MRT (magnetic resonance tomography) treatment room at Saint Mary's Hospital in Hamburg. Positive side-effects include lower energy costs and a zero maintenance requirement.

[60] Different coloured LEDs in the examination luminaire help doctors assess the condition of skin and wounds.

# LED Special: Operating Devices and Ballasts

The way LED modules work in luminaires is crucially influenced by current and voltage supply. Electronic operating devices ensure optimal luminous efficacy and longevity by precisely defining electrical parameters. “Intelligent” management can significantly enhance efficiency and comfort even more.

The kind of operating gear selected is determined by the type and application of the LED luminaire. Luminaires can be supplied directly with mains voltage – if the operating gear is integrated in the luminaires – or they can work on a safety extra-low voltage delivered by external operating devices. LED modules are dimmed by separate control inputs (e.g. DALI, DMX) or by pulse width modulation.

Basically, operating devices for LED modules or LED luminaires guarantee:
> the right power supply for the type of fitting: normally safety extra-low voltage (SELV),
> reliable operation even where ambient conditions are difficult,
> LED control, depending on type, and interfaces for management systems,
> a long life tailored to the light source so that LEDs can be used effectively.

Operating devices are either integrated directly in the printed circuit board (PCB) assembly of the LED modules – as in the case of LED modules in capped designs (retrofit lamps) – or designed as separate components.

A distinction is made between operating devices that form an integral part of a luminaire, devices that are incorporated in a luminaire and devices that are independent. Integral operating devices cannot be removed from a luminaire intact, incorporated operating devices can be removed or replaced with the help of tools. Where incorporated or independent operating devices are used, luminaires need to meet safety-relevant requirements.

Separate operating devices meet the safety-relevant requirements of international standards by virtue of their design and can thus be installed outside luminaires or equivalent fittings.

Apart from the constructive design of operating devices, the supply voltage of the LED modules is a matter of major significance.

**Reducing mains voltage**

There are two types of operating device for transforming mains voltage for LEDs:
> *operating devices with constant output voltage* reduce the mains voltage from 230V to a stabilised low voltage such as 10, 12 or 24V. These operating devices are normally used for LED modules with current-limiting devices on the PCB.

LED modules that are operated on a constant low voltage *need to be voltage controlled*. They permit only simple regulation of light intensity by pulsing (i.e. turning on and off) the voltage. This operating mode requires a current limiting device in LED modules because some LEDs have a wide forward voltage spread. If the current limiter settings are wrong, diodes and operating devices may be destroyed. So only operating devices that are specifically designed for the LEDs in question should be used. As a general rule, LED luminaires with a power rating of less than 0.5W are voltage-controlled.

> *operating devices with constant output current* produce a stabilised output current from the 230V mains voltage. The constant output currents realised are typically 350 milliampere (mA), 700 mA or 1,050 mA. With this variant, LED modules can be operated direct and the LEDs switched “in series” – up to the maximum no load voltage of the operating device. The devices are also typically limited to a safety extra-low voltage.

Current-regulated control of LED modules offers more advantages in constant operation and scores points for efficiency (lumen/watt) because there are no power losses due to current-limiting devices. Thanks to a stable operating current, there is also no risk of the diodes being overloaded; fluctuating forward voltages are not an issue here. Current-regulated control is particularly suitable for high-performance high-current diodes.

It is worth noting that all operating devices on the market that meet the relevant safety requirements and have a safety extra-low voltage (SELV) output ensure safe supply line isolation. They have an internal transformer. So even non insulated LED modules can be safely accessed.

**Lighting management**

LEDs permit virtually limitless combinations of brightness and colour. Lighting management ensures the right light at the right place and the right time. “Intelligent” management systems offer four major advantages:
> simple adjustment of lighting to suit different tasks or times of day,
> high cost and energy savings,
> dynamic lighting control,
> high flexibility.

Depending on the assignment, solutions can be realised for specific luminaires, individual rooms, entire buildings or outdoor installations – with control ranging from individual light points to programmed lighting scenes. LEDs thus offer efficient solutions for standard-compliant general lighting

as well as for customised accent lighting and lighting scenarios.

**Dimming and colour control**

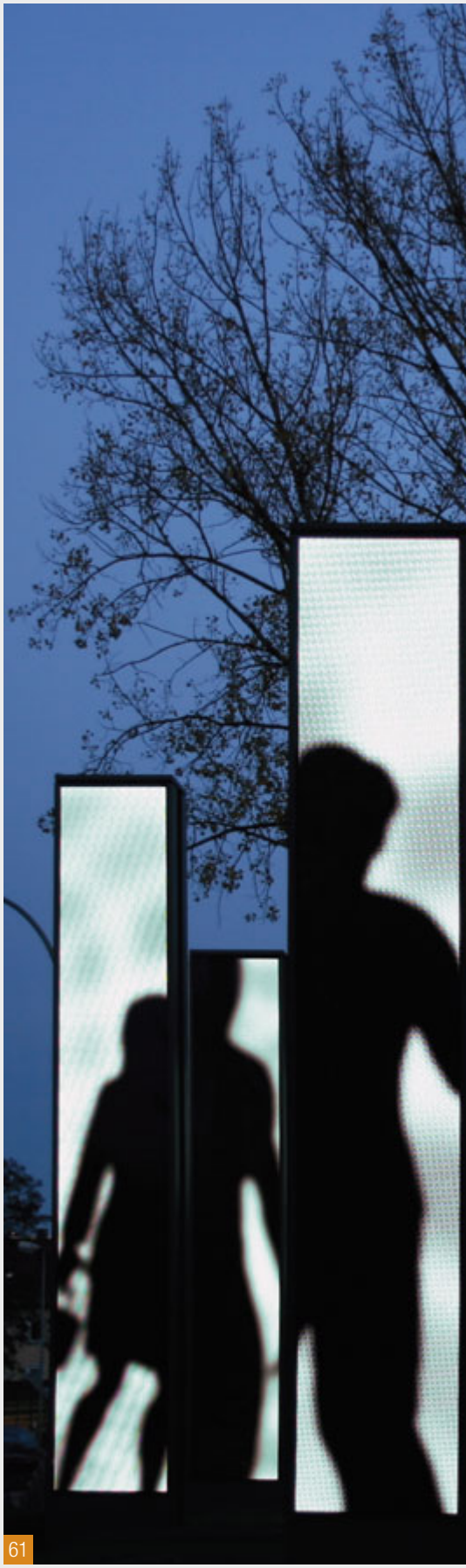
As a general rule, lighting control is possible only if luminaires are designed for switching or dimming – either manually or by timer, computer or sensor. Light intensity is regulated by appropriate sensors: depending on time, human presence or daylight. LED luminaires are normally dimmed by the very efficient, low-loss method of pulse width modulation. Here, the lighting is digitally activated and deactivated at such a high frequency that the flicker is imperceptible to the human eye.

Coloured lighting scenarios are also possible – e.g. through the use of RGB systems controlling identical or different coloured LED modules in three- or multi-channel operation. With additive colour mixing and precisely controlled brightness control of red, green and blue, up to 16.7 million colours can be produced. From delicate lilac through orange to midnight blue – LED light harnesses pale and bold colours in sharply contoured or subtly blurred arrangements to create fascinating atmospheres with a soothing or stimulating effect. Dynamic colour sequences are particularly appealing. Depending on how the control unit is programmed, they can change almost imperceptibly at predefined intervals of seconds, minutes or hours.

**Control system interfaces**

Appropriate interfaces enable LED luminaires to be easily incorporated into modern control systems. The simplest systems from a technological viewpoint are analogue interfaces such as the 1-10 V interface for dimming LEDs. Combined with a sequencer, this also permits dynamic colour sequences. In many cases, signal receivers can also be installed in existing LED luminaires or junction boxes. Multifunction switches or remote control devices can then be used to adjust the lighting as required.
Digital control systems offer a great deal more performance. They integrate lighting management into modern BUS control systems that meet the rising standards of comfort and efficiency required in building services and facility management. For room-related applications or relatively small building solutions, systems that work with the DALI digital interface (the acronym stands for Digital Addressable Lighting Interface) are a suitable choice. DALI can control a large number of control circuits individually via a small number of lines even over long distances. With the help of a central control element, programmed colour sequences and brightnesses can thus be realised as required without difficulty; even energy saving presence and daylight dependent regulation is possible with the right control equipment.

Among the more expensive systems available is the multiplex transmission system DMX. Developed in the United States, it was initially used mainly for stage lighting. Today, DMX is also often used by architects and lighting designers who wish to harness the opportunity it offers to control as many as 512 channels with rapid signal sequences from a single central control unit, realise colour mixes and automate fades and cross-fades. For large-scale applications, DMX units can be linked together. Both DALI and DMX can be integrated in higher-level building management systems such as KNX. These systems network all technical components and control heating, lighting, blinds, ventilation and security systems as required. They thus offer a high degree of comfort and convenience in conjunction with maximum efficiency.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[61] A marriage of art and technology: six-metre-high stelae used for revolving art installations in Munich. The stelae are fitted with the latest LED lighting technology and digital control systems. They can be programmed to display static or moving images.

62

# LEDs for House and Home

Great lighting and major energy and electricity savings – LEDs make it possible. They are a star turn in the home – not just as mood lights for special accents but also in kitchens and bathrooms or as end-to-end energy-saving solutions for high comfort and convenience.

[62] An elegant solution for this outdoor area is provided by translucent surface-mounted ceiling luminaires of extremely shallow design with spraywater protection to IP 44. Each unit has a power rating of just 9W and easily replaces a 50W halogen lamp.

[63] LED solution for the hallway: the surface-mounted luminaires on the ceiling radiate their energy-efficient light directly downwards and use a secondary indirect beam to brighten the ceiling and walls. Wall luminaires set close to the floor provide additional brightness.

[64] Mobile LED luminaires are a flexible option that can bathe rooms in coloured light.

[65] The LED desktop luminaire provides energy-efficient light for working.

"Here I am Man, here dare it to be". Goethe's words read as if they were written about the privacy of the home – because whether we live in a rented apartment or a privately owned house, what matters in the domestic environment is a sense of security and surroundings shaped by personal style. Perfect, then, that modern LEDs offer the right solution for every kind of home and every taste. The tiny diodes enhance every atmosphere – from minimalist Bauhaus to cosy country cottage – as well as offering maximum flexibility and low power consumption.

**LEDs for every kind of home**

Purists delight in the fact that LEDs, embracing the maxim "form follows function", make life easier while discreetly emphasizing architecture and furnishings. Slender lighting strip allows light to flood from suspended ceilings or narrow wall outlets, minimalist LED downlights brightly illuminate the entire dining table, flush-mounted recessed spots direct light onto staircase treads and draw attention to pictures and sculptures.

Colour lovers enjoy the feel-good partnership of "light and colour" and the range of more than 16 million possibilities offered by LEDs. They know that coloured light prompts the human body to secrete mood-brightening substances. A second with the remote is all it takes to change living room lighting from meditative blue to rousing red.

Anyone wishing to bathe whole ceilings or walls in a favourite colour needs high-intensity RGB floods. Mobile LED luminaires are a practical alternative to permanently installed systems. They enable pools or splashes of colour to be added as and where required.

**Robust, efficient and with a long life**

Environmentalists are not the only ones delighted with the many "green" qualities of


63


64


65

sustainable LED solutions: compared to incandescent lamps, they make for an energy saving of 80 percent. That eases the pressure on both the environment and the household budget. For ultra-low-energy "passive" houses, LEDs' low heat gain is an important advantage. As for lamp replacement and disposal, these are hardly an issue with LEDs because they have a service life of 50,000 hours or more. Switched on for three hours a day, they have a life expectance of no less than 45 years. An incandescent lamp, by comparison, lasts for around one year. Another environmental advantage is that, unlike energy-saving lamps, diodes contain no mercury. So they do not need to be disposed of as special waste at the end of their life.

LEDs are also convincing in terms of lighting quality. With warm white light colour and good to very good colour rendering, they produce a fresh, natural light. Diodes also give a 100 percent performance from the moment they are switched on. And frequent switching – e.g. under the control of a motion detector – does not shorten the robust light source's life, which is not the case with energy-saving and fluorescent lamps.

**LEDs in and around the home**

In new buildings, lighting installations incorporating LED and lighting control systems offer maximum efficiency, convenience and comfort. With a building management system, for example, a variety of lighting atmospheres can be defined for the entire building. From "bright" in the morning to "cosy" in the evening, the different atmospheres can be selected by residents at any time and for any area at the push of a remote control button.

However, LED solutions can also be integrated in an existing home without major refurbishment work. One option is to use compact surface-mounted and recessed luminaires, which are available for both indoor and outdoor use; another is to install mobile luminaires, which have no difficulty whatsoever finding a place in the home. Kitchens and wardrobes can be bathed in light and colour by flexible LED modules.

It is also easy to replace old "light bulbs" in existing luminaires with power-saving LEDs: LED lamps are available today with a screw or pin base and in a whole range of white tones, colours and even colour-changing designs. A 60W incandescent lamp can thus be replaced in seconds by an LED lamp that delivers the same radiant flux but requires only 8 watts of electricity to do so.

[66] Agreeable uniform light is provided in the bathroom by LED wall luminaires with integrated converter. The slender luminaire head can be swung forward and positioned at any angle.

[67] The compact design of LEDs paves the way for totally new, slimline luminaires. The height-adjustable pendant luminaire over the dining table is only five centimetres wide but emits extremely intense light and consumes very little electricity.

[68] Recessed floor luminaires set the scene in the entrance area and guide visitors into the home.

66

67

## Energy cost comparison for a three-room apartment

In domestic lighting, efficient LEDs score points not only because of the lighting quality they deliver but also because they save a great deal of energy and therefore electricity costs. The example shows the lighting costs for a 58 sqm three-room apartment over four years.
(assuming an electricity price of 0.21 €/kWh and 1,460 luminaire operating hours a year)

| Room | LED solution | Conventional solution |
|---|---|---|
| Kitchen | 32 W | 194 W |
| Bathroom | 20 W | 90 W |
| Hall | 24 W | 150 W |
| Living room | 48 W | 210 W |
| Bedroom | 44 W | 235 W |
| Children's room / home office | 23 W | 102 W |
| Balcony | 16 W | 60 W |
| Converter / ballast | 31 W | 104 W |
| Total wattage | 238 W | 1,145 W |
| **Approx. electricity costs over 4 years** | **€ 292.–** | **€ 1,404.–** |
| **Saving** | **€ 1,112.–** | |

68

# LEDs in Industry and Trade

Lighting for workplaces in industry and trade needs to meet the highest requirements in terms of quality and reliability. At the same time, workplace lighting should be energy efficient and have low maintenance requirements because downtimes are something that no company can afford any more.

For global player and regional dental laboratory alike, competition demands precision-made quality products at reasonable market prices. Manufacturing structures need to be optimised down to the last detail, which means that lighting is constantly reappraised. Correct lighting has been shown to help lower error and sick rates. It also boosts the performance of every employee.

LED solutions for general lighting are still a rarity in industry but they are an increasingly popular choice for workplace oriented lighting. The tiny diodes score points for their extremely long life of 50,000 hours or more, their low power consumption and the constant high lighting quality they deliver. Their strengths save both maintenance and operating costs.

Another important point is that LEDs are not sensitive to vibration or shock, so they are optimally suitable for workplace lighting in a manufacturing environment. What is more, they project no beam heat – an important advantage especially inside large machines, where the use of LEDs helps prevent coolants and lubricants being baked onto surfaces.

**High-intensity point lighting**

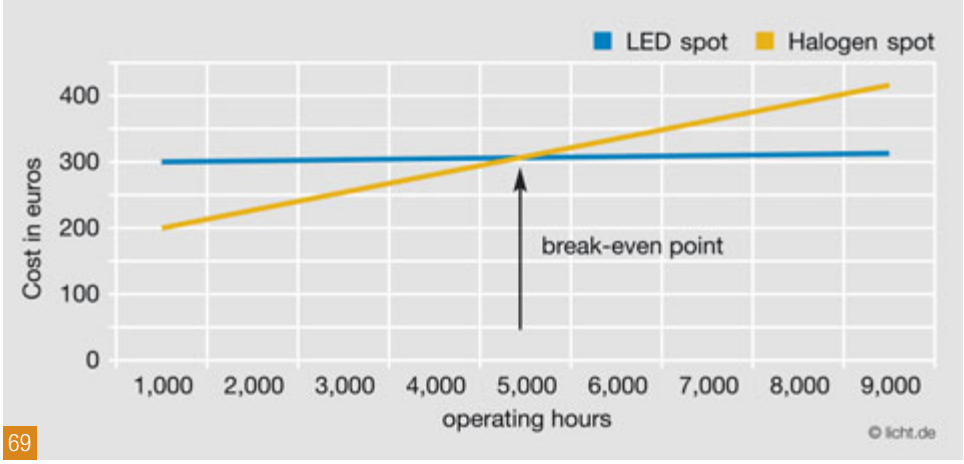
High-frequency operation means that LEDs produce uniform flicker-free workplace light and thus prevent potentially dangerous stroboscopic effects. This reduces the risk of accidents during the installation and maintenance of machines. Glare free and producing a very intense beam of light, LEDs also facilitate work wherever minute details need to be reliably recognised and the highest visual performance is required, e.g. in jewellery making or prosthetic dentistry.

New LED luminaires permit precise adjustment to the requirements of trade and industry. Flexible luminaire head joints ensure that light is directed exactly where it is needed; robust articulated rod and head assemblies are the right choice for large-scale facilities. High degrees of luminaire protection (see also page 51) prevent the LEDs being damaged during grinding, engraving or sawing operations.

With sophisticated electronics, LED luminaires can also be connected directly to a 24 V d.c. or a.c. power source. In comparison to conventional light sources, this means fast and flawless installation with low maintenance requirements.

**Cost comparison**

| | LED spot | Halogen spot |
|---|---|---|
| Purchase price | € 300,– | € 200,– |
| Wattage (w) | 3 x 3 W | 20 W |
| Light source lifespan | 50,000 hrs | 2,000 hrs |
| Maintenance costs/lamp replacement | – | 25 x € 45.– = € 1,125,– |
| Total cost over 50,000 operating hours at 0.18 €/kWh | € 381,– | € 1.505,– |
| **Saving** | **€ 1,124.–** | |

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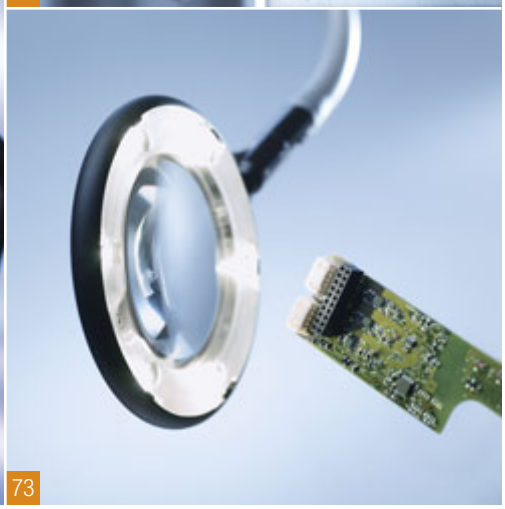


[69] A direct cost comparison over 50,000 operating hours shows that an LED spot saves more than € 1,000 compared to a halogen spot. LEDs lower both energy consumption and carbon emissions.

[70] The minimal dimensions of LED luminaires are an advantage especially in machinery and plant engineering. Other plus points, in addition to high lighting quality, are shock resistance, IR- and UV-free light and no projected beam heat.

[71] High-power LEDs beat conventional light sources hands down in terms of luminous efficacy and longevity. The light of an LED spot is five times more intense than that of a halogen lamp.

[72] Slimline hybrid solution for industry. The wall luminaire incorporates a fluorescent lamp for planar lighting and LEDs for directional point lighting.

[73] The 6-LED magnifying luminaire focuses light precisely on the inspection plane.

74

# LEDs for Emergency and Safety Lighting

Safety and accident prevention are important lighting tasks. With diminutive dimensions and a long lifespan, LEDs provide more scope for luminaire design and reduce operating costs.

Wherever people are present in large numbers, safety lighting is a must. Its moment comes when mains voltage fails. In that event, it needs to be activated immediately by a standby power source. Routes out of the building are marked by escape signs; supplementary safety lighting helps avoid panic, facilitates orientation and lessens the risk of accident.

Escape sign and emergency luminaires are often in operation 24/7. So it is not surprising that long-life solutions like LEDs are increasingly the option of choice for such applications. Provided that thermal management is effective and high-quality operating devices are used, LED systems have a lifespan of 50,000 hours or more. In practice, this means lower maintenance costs, optimised lighting and a reduced energy bill.

**Escape signs**

The small dimensions of LEDs permit visually discreet escape sign luminaires of formally reduced design. At the same time, manufacturers face the challenge of transforming the punctual luminance of LEDs into a uniformly bright luminous surface while also ensuring compliance with the relevant standards. Escape signs need to be clearly identifiable even when general lighting is switched on; the required average luminance needs to be at least 200 cd/m² – and 500 cd/m² for the white parts of the sign. So luminous flux should decrease as little as possible over the life of the LEDs. In quality lighting systems, this age-related fall in LED luminous flux is taken into account by allowing an extra margin for degradation. Alternatively, many systems work with what is known as a maintenance function: they make up for the decrease in LED luminous flux by dimming the diodes at the outset to around 70 percent of their capacity and then raising it gradually to 100 percent over the course of their operating life.

**Emergency luminaires**

In emergency lighting, LED solutions help save energy. LED luminaires with a low connected load permit efficient, eco-friendly installations. To achieve the optimal efficiency of LED luminaires, additional optics and reflectors may be needed so that the number of luminaires installed can be reduced – without prejudicing compliance with normative and statutory emergency lighting requirements.

Thanks to their small dimensions, LED emergency luminaires keep a low profile. They thus offer the designer greater freedom.

*More information and planning tips can be found in booklet 10 “Emergency Lighting, Safety lighting” of the licht.de series of publications. It is available for download at www.licht.de/licht.wissen.*

75

[74] The formally reduced design of the LED escape sign luminaire blends seamlessly with the modern architecture.

[75] Energy-efficient LEDs are increasingly the solution of choice for emergency and safety lighting. Their longevity cuts maintenance bills.

# LED Special: Safety, Marks of Approval and Standards

LED lighting really only plays out its advantages where light sources, modules, luminaires and operating devices are of impeccable quality. Standard-compliant products and professional installation prevent malfunction and guard against health risks.

[76+77] Danger arises where water and electricity meet. So luminaires for use in bathrooms or outdoors need to be suitably well protected. Pointers for safe operation are provided by IP degrees of protection.

76

It is worth paying attention to quality when selecting lighting equipment, especially for LED applications. Many of the LED products now on the market do not meet statutory requirements and, in some cases, are seriously flawed. But modules with insufficient insulation, badly designed luminaires or poorly made operating devices do more than just impair LED longevity and light output; they can actually constitute a real hazard, present a health risk or even cause a fire.

LED modules, luminaires and operating devices need to conform to the relevant standards of the IEC (International Electrotechnical Commission). Marks of conformity and information about classes and degrees of protection need to be displayed on the product label. They are listed and described below:

**ENEC/VDE test mark**

The ENEC mark (ENEC = European Norm Electrical Certification) shows that luminaires and built-in operating devices comply with current standards. The number after the mark identifies the testing agency responsible. In Germany, this is VDE (Verband Deutscher Elektrotechniker), which combines its mark with the ENEC symbol. VDE not only tests products in Germany; it also monitors their production.

**GS mark**

The GS mark (= Geprüfte Sicherheit) may only be used in conjunction with the mark of an authorised testing agency. In Germany, for example, this could be VDE or TÜV. The GS mark is used to confirm that the product tested conforms to the German Equipment and Product Safety Act (GPSG).

**EMV mark**

The EMV mark guarantees the electromagnetic compatibility of luminaires and operating devices. To be eligible to display it, a device must not emit any electrical or electromagnetic noise or signals that could damage or inferfere with other appliances.

**CE mark**

The CE mark is not a test mark but is essential for products marketed within the EU. It is applied by manufacturers and importers to certify that their products meet the “fundamental requirements” of certain EU directives. These include, for example, the Eco-design Directive and the EMC Directive. Manufacturers and importers need to present evidence of conformity to the relevant government agencies on request.

**Classes of protection**

Luminaires and operating devices are electrical products, which need to be adequately insulated to ensure safe operation. DIN EN 61140 divides them into three classes of protection.

**Class I**

Luminaires for connection to the line-side PE conductor. Live parts can be touched even if the basic insulation fails. They do not carry dangerous voltages. The symbol is shown at the point of connection.

**Class II**

Luminaires in which live parts are furnished with additional or enhanced insulation. They have no PE conductor terminal.

**Class III**

Luminaires operated on a safety extra-low voltage (SELV). The supply voltage downstream of the operating device must be no higher than 50 V.

**Fire protection symbols**

Where LED modules or luminaires are installed in or on furniture, they need to meet certain thermal requirements and be labelled accordingly. The following table shows what the individual symbols stand for.

| Mounting surface | | Luminaires with the marks | | | |
|---|---|---|---|---|---|
| Flammability | Example | none | F | M | M M |
| non-flammable | concrete | x | x | x | x |
| > 200°C | wood | | x | x | x |
| < 200°C | textiles | | | | x |

To eliminate fire risk, a stipulated minimum distance from other components needs to be observed.

**Degrees of protection**

Not all LED luminaires can be used in a bathroom or garden. Pointers for safe operation are provided by IP degrees of protection. The first numeral indicates the degree of protection against solid bodies and contact, the second attests to the degree of waterproofness.

| 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 |

**Standards**

Standards set out the requirements that products and services need to meet. LED luminaires and operative devices, for example, need to satisfy certain requirements in terms of radiation safety. Various standards need to be observed both in the production and in the application of LED solutions:

**Luminaires:** DIN EN 60598. Luminaires – Part 1: General requirements and tests; Part 2: Particular requirements.

**LED modules:** DIN VDE 0715-100. LED modules for general lighting – Safety requirements.

**Sockets:** DIN IEC 60838-2-2. Part 2: Particular requirements. Section 2: Connectors for LED modules.

**Operating devices:** DIN EN 61347-1. Lamp controlgear – Part 1: General and safety requirements.

DIN EN 61347-2-13. Lamp controlgear – Part 2-13: Particular requirements for d.c. or a.c. supplied electronic controlgear for LED modules.

**EMV-relevant standards:** DIN EN 55015. Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
DIN EN 61547. Equipment for general lighting purposes – EMC immunity requirements.

DIN EN 61000. Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions. Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems for equipment with rated current < 16A per phase and not subject to conditional connection.

*For more information and links about standards and marks of conformity, go to the www.licht.de website.*

77

# LEDs for Automobile Lighting

Seeing and being seen clearly – optimal lighting is a safety factor at least as important to motorists as effective brakes and good tyres. LEDs are rapidly conquering the realm of automotive lighting – as brake lights, daytime running lights and in headlights.

Pole position for the LED. Used for years to illuminate displays, switches and buttons, light-emitting diodes now provide signal light in indicators and brake lights and are also starting to take off as a light source for outdoor luminaires. The first vehicles with efficient multichip headlights are already on the roads.

**Agreeable light, optimal visibility**

With a colour temperature of around 6,000 kelvin, LEDs emit a very bright light that motorists find very agreeable. It enables them to make out the road ahead, the edge of the carriageway and any upcoming obstacles better at night and is less likely to cause visual fatigue. Studies show that serious accidents at night can be significantly reduced by the use of higher-temperature headlights.

LEDs also set safety standards in rear lights, providing immediate bright light on braking. The motorist behind thus receives the early warning needed for a swift response. Valuable seconds are saved.

**Saving fuel and servicing**

Light-emitting diodes have a lifespan of thousands of hours and save the motorist expensive servicing and replacement lamps.

Their compact dimensions also permit stylish new luminaire designs – from pixelated look to luminous front line. Because LEDs lend themselves well to dimming, it is possible to integrate a number of functions in a single LED module. Depending on variant and requirements, the range of achievable luminance extends from 125 lumen for single chip modules to 1,000 lumen for five-chip models. With an intelligent control system, brightness can be regulated and is optimally suitable for all main headlight functions from high beam to fog light. Daylight running light can be realised, for example, by dimming the low beam in the main headlight. That makes additional components unnecessary and saves space in the engine compartment.

One very important point is that efficient LEDs consume a great deal less energy than conventional lamps. This makes a considerable difference where daytime running lights (DRLs) are concerned. For safety reasons, the use of DRLs has been recommended in Germany since 2005; as of 2011, they are required to be a standard feature of all new vehicles in the EU. Anyone using special LED luminaires for daytime running light has a lower environmental impact and smaller fuel bills than a motorist using conventional lamps.

Experts anticipate further major improvements in the efficiency of LEDs for automotive lighting. They already achieve a luminosity of 80 lumen/watt (lm/W) and are expected to reach 200 lm/W in a few years' time. To give this perspective: a conventional halogen lamp produces 23 lumen from a single watt of electricity, a xenon burner produces 83 lumen.

**"Intelligent" headlights**

LEDs will increasingly blaze a trail for intelligent front lighting systems capable of adapting flexibly to motoring needs. Once installed, the light-emitting diodes will permit the realisation of not only high beam, low beam and daylight running light but also supplementary curve lighting that dispenses with the complex mechanics and servomotors required by conventional systems.

It will be possible in future to drive on high beam at all times outside built-up areas –


78

80

even in the presence of oncoming vehicles or other motorists ahead. This is because LED pixels are activated and deactivated individually as required. So we are on the threshold of having access to the first glare-free high beam that illuminates only the area of the carriageway where it is actually needed.

Vehicles ahead can thus be simply “masked out” while the motorist himself enjoys optimal visibility to left and right and, thanks to the bright LED light, is able to recognise obstacles far more quickly than with conventional low beam light. Such a system requires a camera pointed in the direction of travel and modern electronics networking the navigation system with the curve lighting function and processing the information from light-based driver assistance systems.

In the future, LED technology could thus offer a standard of safety never achieved in the past.

[78] Stylish design and economical on energy: an efficient LED headlight.

[79] High-performance modules permit new applications, such as daylight running or even low beam systems based on LED technology.

[80] Customised interior: the LED lighting suits the style of the vehicle. The coloured light can be easily changed to meet the personal preferences of the driver.

# LED Special: OLED – Technology of the Future

Subtle lighting from living room windows, satnav information displayed on the car windscreen: organic light-emitting diodes (OLEDs) open up whole new realms of opportunity for harnessing light – in the home and at work, on wallpaper and fabrics.

Light = lamp + luminaire? Not for much longer: in a few years' time, ceilings will radiate colour, transparent glass windows will spread a subtle warm white light in the evening, office or kitchen wallpaper will turn into a display screen at the push of a button – and the television set will roll up to fit into a handbag.

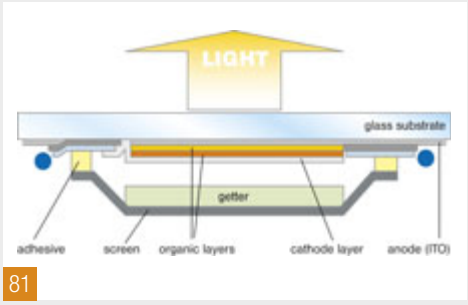
What sound like items on a props list for a science fiction film are already a reality for scientists at universities and corporations. OLEDs unlock the door to exciting new dimensions of display technology and lighting.

OLEDs are the first truly planar light source. Unlike the point light sources realised with inorganic LEDs, they use organic semiconductors to produce light. And they offer many advantages:

> They are extremely thin – the entire device is currently around 1.8 mm thick – and thus also lightweight and aesthetically pleasing.
> They produce uniform, largely glare-free light with a high colour rendering index.
> They deliver their full light output instantly, can be easily and infinitely dimmed by adjusting the operating current and permit extremely flexible colour control.
> They can easily be incorporated into other materials, appear transparent or diffuse during the day and gleam as bright as day in the evening.
> They can be placed close to sensitive materials and touched without risk of burns. The light they produce can be controlled by a hand movement.
> They are environmentally friendly; they contain neither mercury nor other toxic substances and are recyclable.

With these characteristics, OLEDs will not only transform the design and atmosphere of interiors and outdoor space; they will also make a significant contribution to environmental protection.

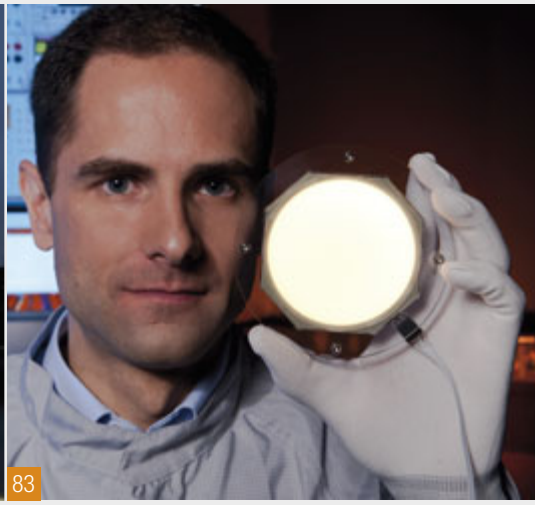
**How OLEDs work**




81

In contrast to conventional lamps, where current is passed through a wire or gas, the current that flows in OLEDs is conducted through ultra-fine layers of organic material – a hundred times thinner than a human hair. As a general rule, OLEDs today are based on small molecules (smOLED); in future, long-chain polymers (pOLEDs) will be an increasingly widespread alternative.

82



83

As Fig. 81 shows, the structure of an OLED resembles a sandwich. The organic layers are always embedded between two planar electrodes: a negatively charged layer of aluminium (= cathode) and a positively charged, transparent layer of indium tin oxide (= anode). The material used for the substrate at present is generally glass. When a voltage is applied, electrons and electron "holes" – positive charge carriers – migrate to the middle of the device, recombine and excite the embedded molecules, causing them to emit light. As with LEDs, the colour of the light produced depends on the molecular structure of the semiconductor used.

Because OLEDs respond very sensitively to oxygen and moisture, they are encapsulated. On the rear of the device is a cushion-like "getter", which intercepts the moisture before it can reach the particularly rust-susceptible cathode.

**On the way to market**

Organic diodes are already used for lights in mobile phones and gameboys. They also have a promising future as ultra-flat displays for television – because unlike LCD displays with conventional backlighting, self-illuminating OLEDs save a great deal of space and energy. The first OLED screens came onto the market in early 2009.

In three to five years' time, experts reckon the luminescent plastics will also start their triumphant march through the world of lighting. Individual prototypes have already been presented but more development work still needs to be done.

Major challenges include extending OLED life and improving the gossamer-thin films' sensitivity to oxygen and water. Suitable plastics need to be found to protect the sensitive organic layers throughout their long life – because as soon as they come into contact with water or oxygen, they rapidly disintegrate.

The development of transparent plastics that provide the necessary protection will pave the way for flexible OLED panels – large, uniformly luminous surfaces delivering light tailored to colour and brightness requirements and capable of being applied to nearly any surface in virtually any shape.

In companies and in national and European research projects – such as OLED100.eu – lighting technologists and scientists are working to drive OLED technology forward fast. Prototypes today achieve 25 lumen per watt (lm/W) efficiency; in current research projects they even reach 65 lm/W. The second goal is to increase longevity significantly beyond the 10,000 hours achieved today.

84

[81] Organic LEDs today are generally based on small molecules. Their structure resembles a sandwich.

[82] A rare sight (for the moment) of OLEDs in action. Organic diodes are the first truly planar light source. They will open up a world of opportunity in lighting design.

[83] Lighting technologists and scientists are working on OLED development.

# LED Special: FAQs about the Light-Emitting Diode

Are LEDs really at the stage where they can be used for general lighting? And is their colour rendering good enough? Here are some answers to frequently asked questions about innovative LED technology.

85

[85] LED fashion: Diodes woven into fabric light up a winter outfit.

**Why should LEDs be used for general lighting? Old incandescent lamps can surely be replaced by energy saving lamps.**

Energy-saving lamps are still certainly a good alternative to the incandescent lamp at present. Eventually, however, they will be superseded by high-performance diodes, which offer a whole range of advantages:

> LEDs will soon be a great deal more efficient; in the recent past, the light output ratios they achieve have doubled every two years,

> the lifespan of LEDs today is already five times long than that of energy-saving lamps,

> LEDs can produce different light colours and coloured light and can be both efficiently dimmed and dynamically controlled,

> LEDs permit directional lighting whereas energy-saving lamps have a diffuse radiation characteristic. With LED luminaires, light is delivered exactly where it is needed. So less light is needed to achieve the required brightness – which saves energy.

**Is it true that LED colour rendering is not very good and that LEDs are only suitable for general lighting up to a point?**

No, that is a mistaken belief stemming from the early days of LED. LEDs today achieve a good colour rendering index ($R_a$/CRI) in the 80–90 range. Even values as high as $R_a$ 98 are now attained – which is very close to the maximum (100) delivered by sunlight. So in that respect, LEDs already outperform energy-saving and fluorescent lamps.

**Isn't white LED light cold and uncomfortable?**

Again, this is a common misconception that has persisted since the infancy of LED technology. Indeed, the opposite is true: LEDs today are available in colour temperatures ranging from 2,700 (= warm white) to 6,500 kelvin (= cold white).

With special modules, the white light colour can even be varied at will: from cool white light for better concentration in the morning to warm white light for a cosy atmosphere in the evening. This flexibility makes the efficient long-life LED a particularly good choice for general lighting in professional applications.

**Do LEDs emit IR and UV rays?**

No, LED light contains no infrared or ultraviolet radiation. Heat is generated at printed circuit board (PCB) level but is not radiated in the direction of the illuminated object. So sensitive and precious objects in museums or shops can be strikingly illuminated with no risk of radiation damage.

It is important to note, however, that all visible light is radiation. So even where IR or UV content is zero, it would be wrong to assume that illuminance can be raised to any level. Having said that, however, LED light is a great deal gentler than the widely used light of low-voltage halogen lamps.

**How long is the lifespan of LEDs?**
LED luminaires have a very long life – up to 50,000 hours or more.

And unlike conventional lamps, LEDs do not fail at the end of it. But even they age. Their light output slowly declines without any noticeable change in the subjective impression of brightness. However, at the end of their rated life, performance is still around 70 or 50 percent. So the LED failure rate is significantly lower, for example, than that of compact fluorescent lamps.

One prerequisite for a long life is precise observance of the installation conditions set out in mounting instructions. Economy-priced LED products often fail to deliver the promised performance because they do not have sufficient heat removal capacity.

**LED solutions are more expensive than conventional lamps. So is the higher acquisition price recouped, e.g. through energy savings?**
LED solutions work very efficiently and are a good alternative to established systems. However, comparison should not be based solely on energy costs. Savings potential is also offered, for example, by LED longevity: this ensures that light sources need to be replaced far less frequently and maintenance costs can be reduced. What is more, LED solutions offer lots of advantages that give them a high added value for particular applications. Those advantages include reliability, dynamic colour and colour temperature management as well as the fact that LEDs emit neither infrared nor ultraviolet radiation.

The use of modern LED technology is increasingly promoted by statutory energy requirements for buildings and the power consumption ceilings they need to observe. The validity of basing appraisals solely on energy cost savings is also called into question.

**Can LEDs fail completely?**
Total failure is very unlikely. The statistical failure rate is around two in a million mounted LEDs.

**What happens when an LED is defective? Does the luminaire need to be replaced?**
If an individual LED does fail or an entire luminaire is defective, the maintenance work needs to be carried out by an authorised professional. In the case of any faults that occur during the statutory warranty period, consumers have a right of remedy. Even after the warranty period expires, an overhaul should also be possible. This matter should be clarified when the luminaire is purchased. Where a component needs to be replaced, account should be taken of the light colour and brightness of the other LEDs in the system.

**Do new LED products differ in terms of lighting performance? What needs to be taken into account?**
LED development is a process of constant optimisation, analogous to the rapid advance of the microchip industry. Performance and efficiency are steadily improving as a result of continuous further development. Manufacturers pass on these improvements to the consumer by always fitting luminaires with the latest generation of LEDs. LED luminaire specifications can thus change. So the rule to remember is: use only the luminaire manufacturer's current data records.

**Do the luminous flux figures given in LED manufacturers' data sheets also apply to luminaires and LED lamps?**
No, a distinction needs to be made between the luminous flux figures that appear in specifications and the actual available luminous flux of an LED luminaire or retrofit lamp ready for use.

The background to this is that the luminous flux figures in data sheets refer to values achieved in the LED itself at a temperature of 25° Celsius. The LED tested is in a "raw" state; it is not mounted on a printed circuit board and not installed in a luminaire or lamp. For specification testing, LEDs are operated on currents considerably lower than the customary 350 mA or 700 mA – and only for a very short time. The results are then extrapolated, which produces values of more than 110 lm/W. Depending on LED type and light colour, temperatures of more than 80° Celsius are permitted to reach the lifespan given. In practical operation, these ceilings need to be observed through the use of efficient thermal management.

In practice, therefore, care must always be taken to distinguish between LED manufacturers' data sheet specifications and the actual luminous flux of a complete luminaire or retrofit lamp. Reputable suppliers provide these figures; less reputable ones may not disclose them at all.

**Is it harmful to the eye to look into an LED luminaire?**
No, LED luminaires spread the light generated by a light-emitting diode and present no problems for the eye. LEDs with a low power rating of less than 1W generally fall into the most harmless LED category (Class I) and have been classed alongside classical light sources since mid-2008. Because of the high luminance, however, it is not advisable to stare directly at an LED light source for any length of time. Having said that, the same advice essentially applies to other, conventional lamps.

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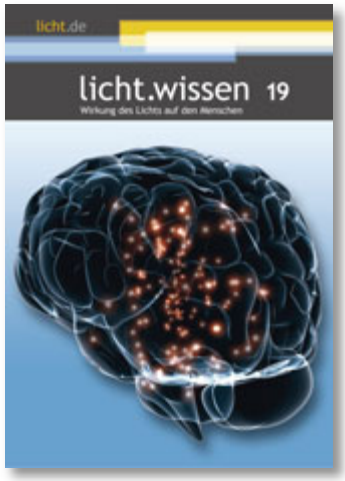


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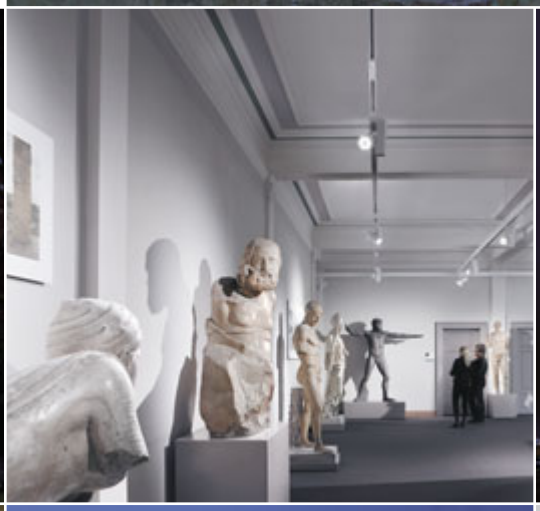

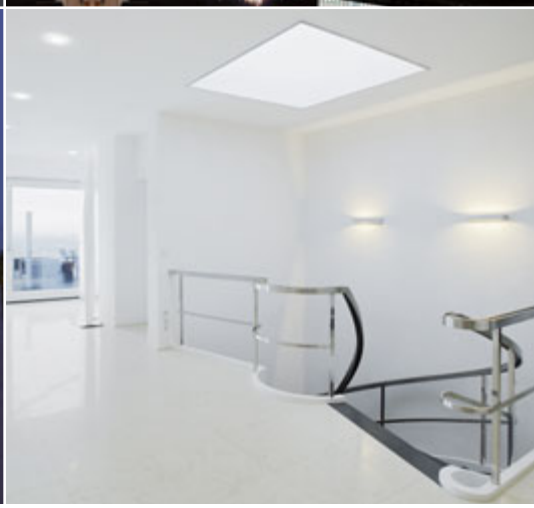

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