# DOSSIER LED

LIGHTING
WITH A NEW
LIGHT SOURCE

Sixth edition, November 2015

ETAP

EXCELLENT LIGHTING, SAVING ENERGY

Preface

*LEDs are the new standard in the world of lighting. Even if technology is slowly reaching maturity, our knowledge of the lifespan, materials and properties of LEDs is still increasing every day. As usual this report provides you with all the necessary information to keep abreast of this complex matter.*

*You would like to know more about the service life of LED luminaires. You wonder what the latest trends are in colour rendering? You would like to know what the legal obligations are with respect to photobiological safety. You will find an answer to all these questions in the sixth edition of this LED report.  We have indicated updates in the margin. The latest version of this publication can be found on our website at www.etaplighting.com*

**Sixth edition, November 2015**

# LIGHTING WITH A NEW LIGHT SOURCE

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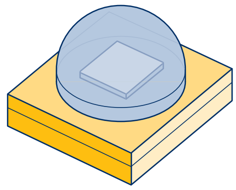
# Section 1: LEDs as a light source

## 1. HOW DO LEDS WORK?



LED stands for Light Emitting Diode. An LED is a semiconductor (diode) emitting light when current flows through it. Semiconductor materials used by LEDs, convert electrical energy into visible electromagnetic radiation, in other words, into light.

The stimulus is therefore created by electric current through the diode (more specifically through the junction). The diode through which the electric current flows is unidirectional, as are all diodes: light will only be created if direct current flows through it in the 'right' direction, i.e., from the anode (positive pole) to the cathode (negative pole).

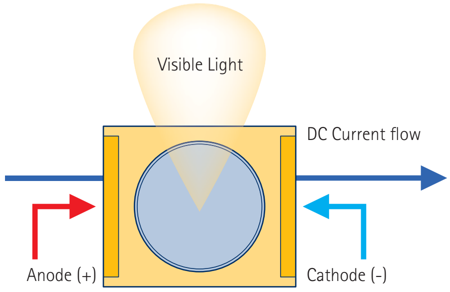



*Fig. 1: How an LED works*

The amount of light generated, is nearly proportional to the amount of current flowing through the diode. For lighting purposes current-controlled supplies ('constant current') are always used (see Section 3).

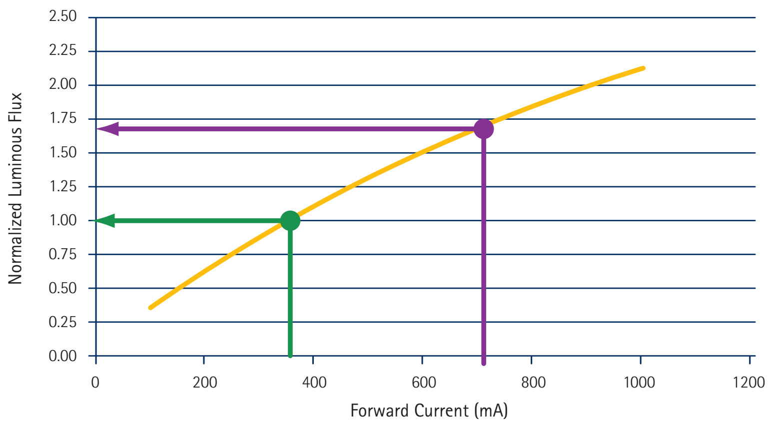



*Fig. 2: Impact of current on luminous flux*

The combination of LED (semiconductor), housing and primary optics is referred to as an LED component. This LED component covers and protects the LED, ensures that the heat generated internally is also dissipated and includes a primary optics system, i.e., a small lens, to collect and emit the light generated by the LED in a defined pattern.

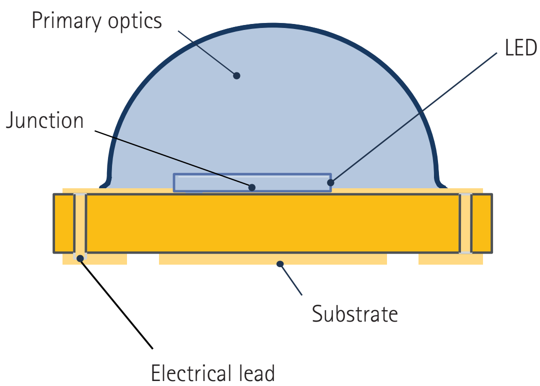



*Fig. 3: Composition of an LED component*



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The LED emits monochromatic light. The colour of the light depends on the materials used during production, which can be all saturated colours from the visible spectrum, from violet and blue through green to red.

White light can be produced as follows:

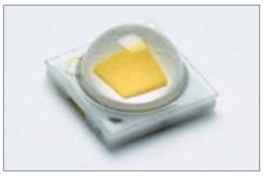
1. Bichromatically:
   - The most prevalent way is to provide a blue LED with luminescent (light-emitting) material, which converts part of the blue light into white (or rather 'yellow') light. The composition of said luminescent material determines the resulting light's colour temperature (to read more about colour temperature, see below in this section).
2. Trichromatically:
   - By blending the colours red, green and blue (RGB).
   - Through combinations of white LEDs in accordance with the first principle with red or amber-coloured LEDs. In this case various colour temperatures are possible with a single module.

## 2. LED LIGHT SOURCES

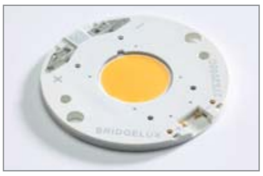
LED light sources can be applied in many ways. According to international standard IEC 62504/CIE TC 2-66 ("Terminology of LEDs and LED assemblies"), the following levels of integration can be distinguished:

**1. LED package or LED component.** This is a single component consisting of one or more LED chips, with or without optics and thermal, mechanical or electrical interfaces.

E.g.



*Cree XP-G LED component*



*Bridgelux LED component*

**2. LED module.** A LED module consists of several LED components, mounted on a PCB (printed circuit board), with or without integrated electronics.

E.g.

*UM2 PCB (ETAP)*

**3. LED lamp.** This is a LED module fitted with a lamp cap.

E.g.

*TG tube light*

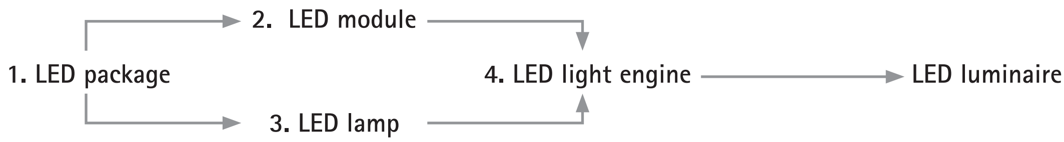
*TG spot light*

**4. LED light engine.** LED module or lamp with driver, suitable for direct connection to the mains voltage.

E.g.

*Osram Prevaled AC*

For the design of a LED luminaire, a lighting manufacturer chooses one of these four levels of integration. Level 1 offers the greatest freedom in terms of creative control, both in the area of design and that of performance and photometrics. Working with levels 3 or 4 provides other advantages such as the logistics capabilities of the supplier and possibly also a lower cost price. For each series ETAP chooses the appropriate level as a function of the end result.




In the majority of cases (e.g., DUAL•LENS or LED+LENS™ luminaires) ETAP develops light engines based on LED packages.

**Construction types in LED packages**

We distinguish three different arrays within the LED package category, depending on power:

- Low-power LEDs (≤ 1W)
- High-power LEDs (1-10W)
- Chip-on-board COB (5-500W)

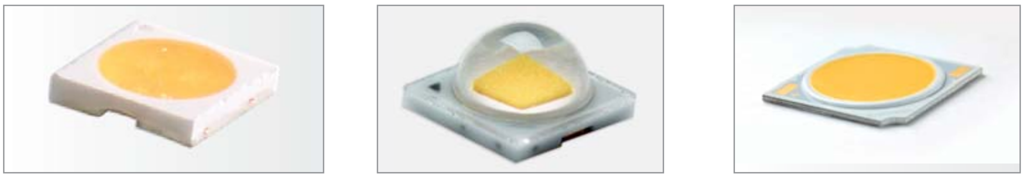


*Fig. 4: LED structure types (from left to right): plastic housing, ceramic substrate, chip-on-board*

In low-power LEDs (Fig. 4 - left) the LED chip is typically installed on a so-called "lead frame" (see Fig. 5), around which a plastic housing is subsequently fitted. The central cavity is filled with a silicone coat containing phosphor. Both lead frame and housing act as reflectors in this design for a portion of the radiating light. That is also the reason why the optical properties - including reflection power and degradation of material – contribute to light maintenance in the long term: the better the material retains its reflecting properties, the lower the degradation.

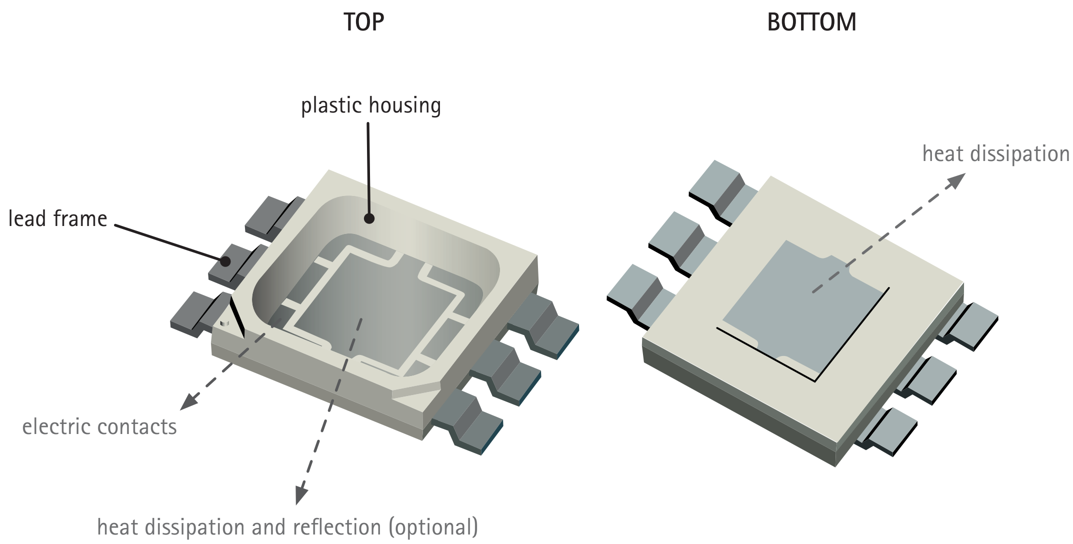



*Fig. 5: LED lead frame with plastic housing (in low-power LED)*

The choice of plastic is also considered on the basis of optical properties, but also cost price and processabililty. The most prevalent materials for housing include thermoplastic materials such as PPA and PCT, and thermosetting resins such as EMC and in some cases even silicones.

The majority of high-power LEDs (Fig. 4 - middle) consist of a LED chip mounted on a ceramic substrate, covered by a phosphor coat and primary optics, generally from silicones. This construction has the following properties:

- Good heat dissipation to the PCB (lower internal thermal resistance)
- Direct emitted light and little reflection
- Good colour stability across the entire cut-off angle

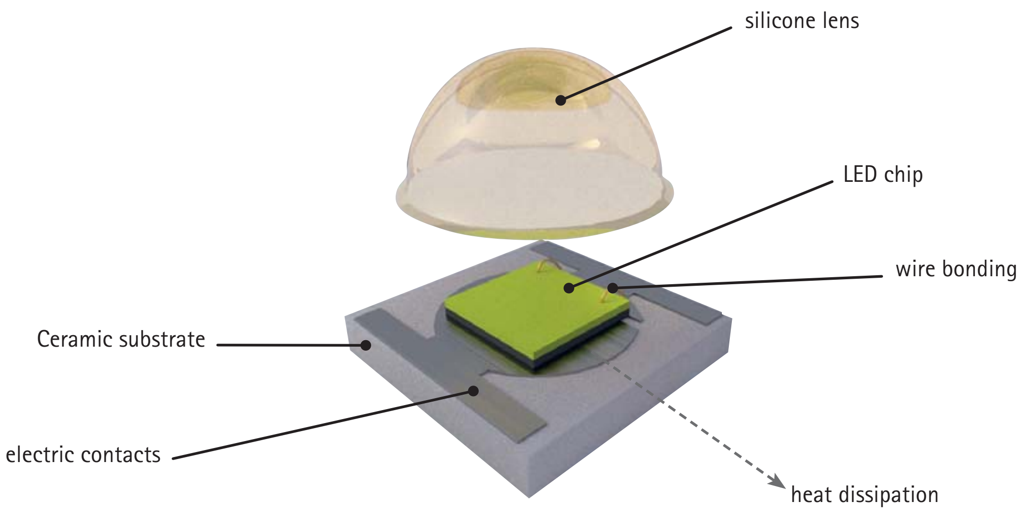



*Fig. 6: Structure of a high-power LED*

The chip-scale package (CSP – see Figure 7) is a miniaturisation of the (low- or high-) power LED. This LED package features minimal housing and is remarkably compact: both chip and substrate are barely 1 $mm^2$ big. In the future even smaller versions will in all likelihood be developed (0.5 $mm^2$).

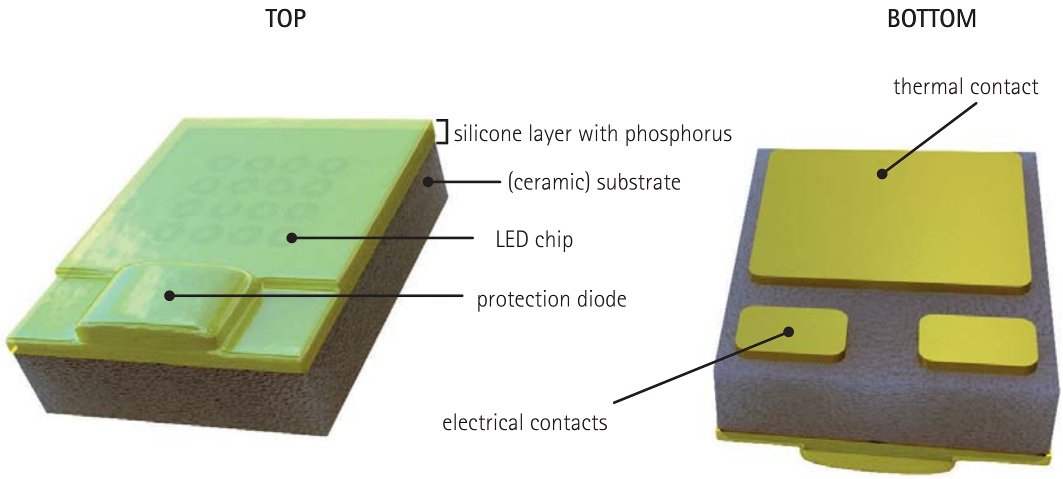



*Fig. 7: Structure of a chip-scale package*

In chip-on-board technology (COB; Fig. 4 - right) several chips are installed on a single substrate and mutually connected. A silicone coat is applied with phosphor. The substrate generally consists of a ceramic material or highly reflective (polished) aluminium.

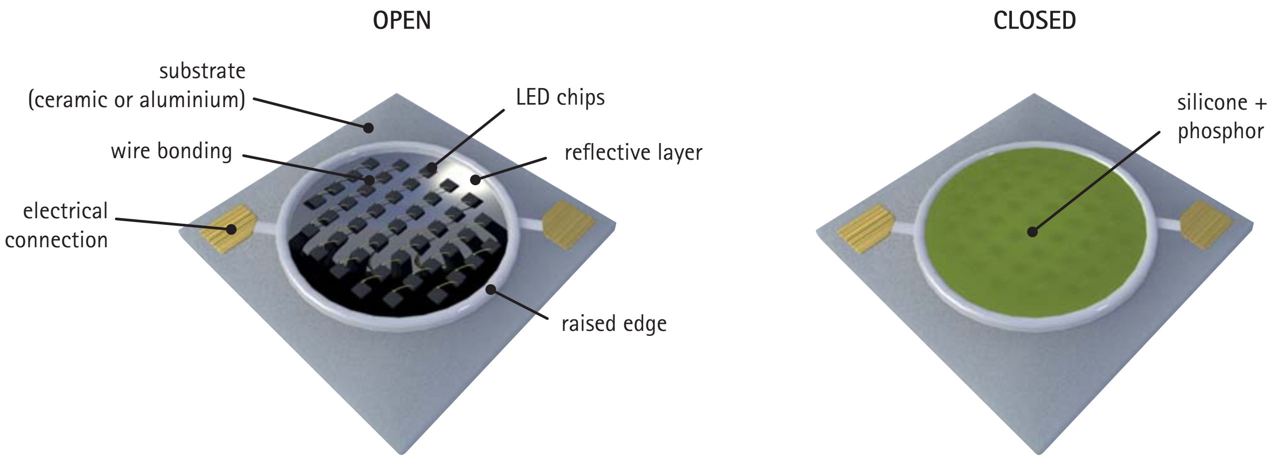



*Fig. 8: Chip-on-board technology construction*

The development of the optical properties in function of time under the influence of light and heat has a major impact on the maintenance factor of LEDs. Stability is optimal for high-power components (e.g., high-power and COB), and lower for plastic low-power LEDs.  Low-power LEDs also result in higher yield with a sophisticated design.

# 3. THE ADVANTAGES OF LEDS

## ADVANTAGE 1: LONG USEFUL LIFETIME

The useful lifetime of LEDs is strongly affected by specific usage conditions, whereby power and internal temperature (and therefore also ambient temperature) are the most important factors. Typically service life of 50,000 hours is assumed. This is understood to mean the time span within which the luminous flux on average drops to 70% of its initial value (see box about MTTF). This lifetime applies provided the LED is used within the postulated temperature limits (typically 80-85°C). If the correct LEDs and good design are used, these values could be significantly higher (see section 4).

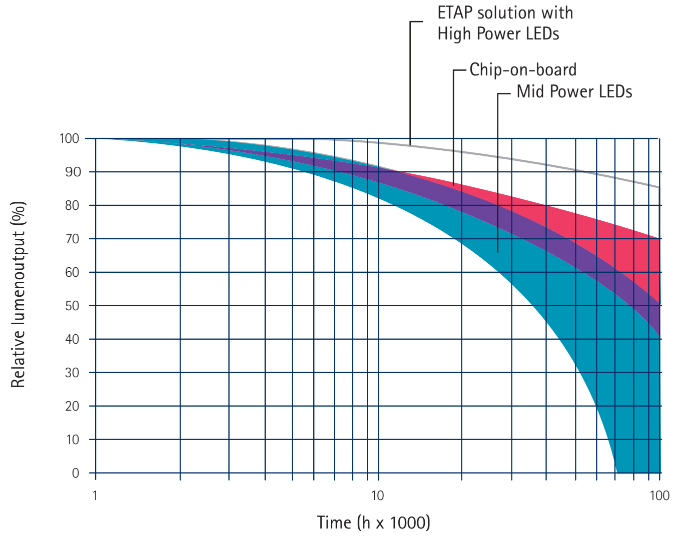



*Fig. 9: Depreciation of the luminous flux over time*

**Useful LED lifetime**
A distinction must be made between parametric failure (light output degradation) and catastrophic failure (LED emits no light) in the determination of the LED lifetime. When manufacturers refer to L70 lifetime they mean the time within which a specific percentage of the LEDs decreases to 70% of the original luminous flux. This percentage of the LEDs is shown in B, e.g., B50 indicates 50%. In the determination of this lifetime, however, no account is taken of any potentially failing LEDs, which are removed from the test. A defective LED is nonetheless important to users. When the lifetime is determined with the inclusion of failing LEDs, reference is made to the F lifetime, which will typically be lower than the B lifetime. For example, L70F10 shows the time span within which 10% drops to less than 70% of the original luminous flux or fails for another reason. International standards and recommendations will increasingly promote and even impose the F definition for the lifetime of LEDs. ETAP specifies no L70/B50 value for its luminaires because this value cannot be used for lighting design. We start from the specified number of burning hours (project specific), from which we calculate the lumen maintenance. For office and industrial applications, the standard burning hours are 25,000 and 50,000 respectively (see also annex 1).

LEDs have a longer useful life, but are sensitive to cyclic thermal stresses and to chemical and electrostatic influences. Touching the LED circuit boards is therefore a fundamental no-no. Direct connection of LEDs to a live supply is to be avoided. Power surges could fully destroy an LED.

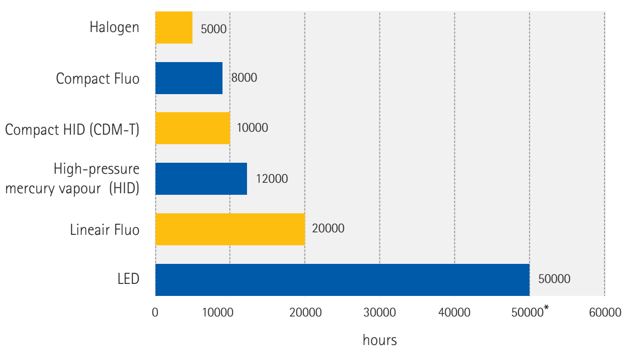



*Fig. 10: Typical values for useful lifetime (simplification)*

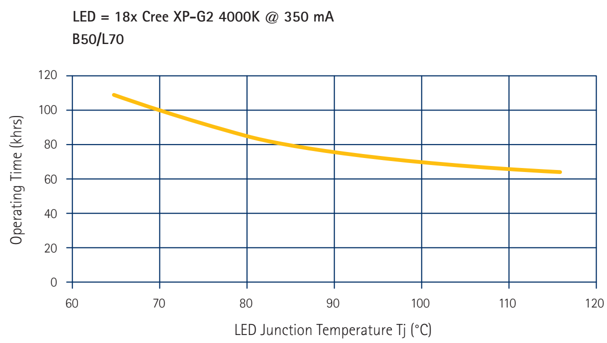
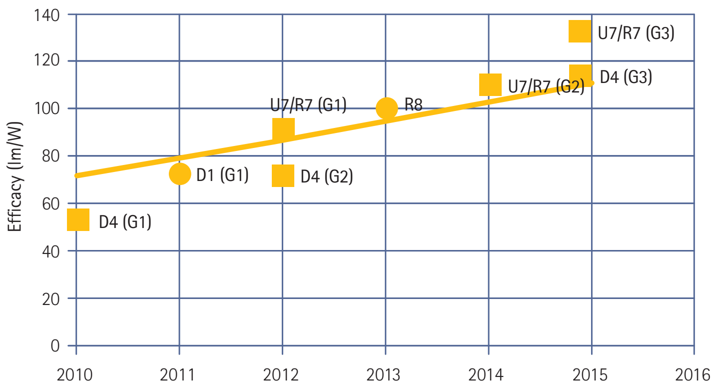



*Fig. 11: Influence of junction temperature on lifetime*

* Based on min. 10,000 hr measurement data (TM-21)

## Advantage 2: High energy-efficiency possible

Cold white LEDs with a colour temperature of 5,000 (kelvin) these days reach more than 180 lm/W under reference conditions. LEDs with a lower colour temperature from 2,700 to 4,000 K (most commonly used for lighting applications in Europe) usually have a lower efficiency. In these colour temperatures, efficiencies of 130 lm/W and more are commercially available today.




This curve is based on the actual performance of the LEDs in concrete applications, which differ from the data published by the manufacturer due to product-specific electrical control and thermal behaviour.

*Fig. 12: Evolution of the specific luminous flux of LED luminaires at 3000 K, with indication of different generations (G1-2-3) of some ETAP products, at junction temperature under normal use (hot lumens)*

**Efficacy: lm/W**

The specific luminous flux reflects the relationship between luminous flux and power consumption. Just as with fluorescents, a distinction must be made between the light source's specific luminous flux (LED component, measured at 25° or 85°C junction temperature and with a standard control current) and that of a luminaire, including driver and optics.

As an illustration an example of U7 with LED:

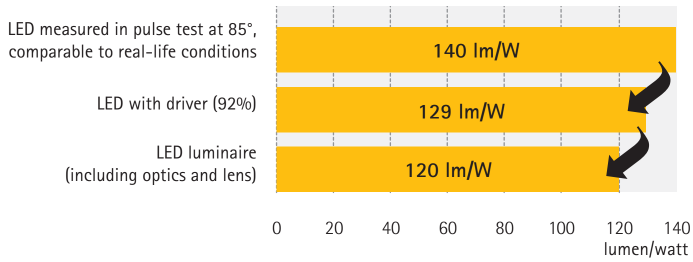



*Fig. 13: U7*

For comparison: U5 reflector luminaire with fluorescent lamp 1 x 32W

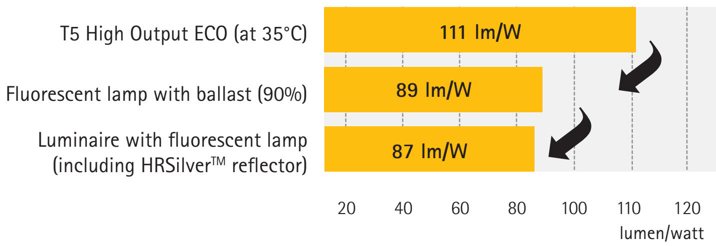



*Fig. 14: U5 reflector luminaire*

Contrary to fluorescent lighting the output of an LED luminaire is determined by the total design: luminous flux density, optics and thermal management. Whilst the lamps are always designed for a working temperature of 35° in fluorescent lighting (influence of thermal management = 1) and control is always nominal (34W lamps are controlled by 34W, hence influence of control = 1), the output in LED lighting is strongly determined by luminaire design.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LEDs with high colour temperature and therefore colder light have a higher efficiency level than the same LEDs with lower colour temperatures. The luminescent material used to create warm white, contains more red and the efficiency of this red component is lower than that of yellow, which is why the overall efficiency of the LED drops.

By way of comparison:

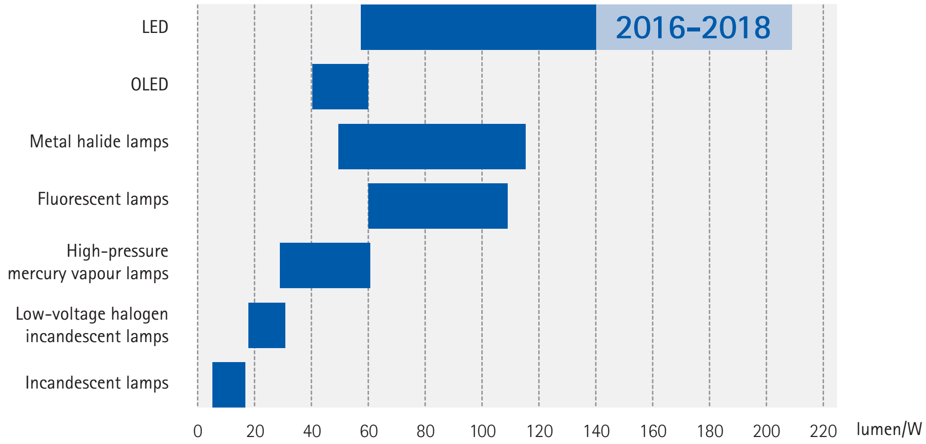



*Fig. 15: Typical values for efficiency of light sources*

## Advantage 3: Good colour quality, choice of colour temperature

**Colour temperature**

The colour temperature of a light source for white light is defined as 'the temperature of a black body of which the emitted light produces the same colour impression as the light source'. Colour temperature is expressed in kelvin (K). Bluish light has a higher colour temperature and is experienced as 'colder' than light with a lower colour temperature.

There are various subdivisions and designations, each with its reference to recognisable colour temperatures:

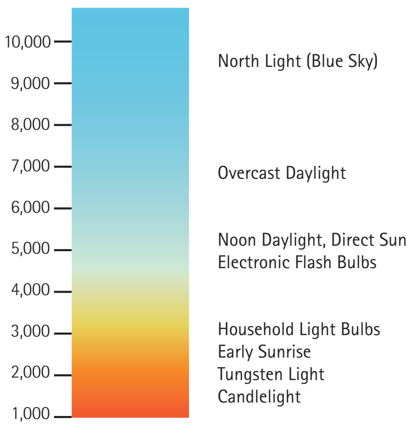



*Fig. 16: Indication of colour temperatures*

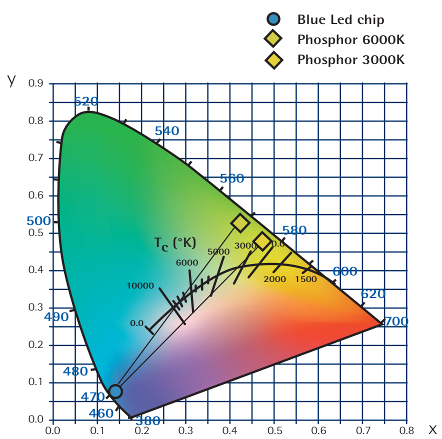
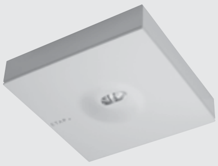



*Fig. 17: Principle of the generation of white light by means of luminescent material*

For white light in RGB LEDs (in which the colours red, green and blue are mixed) all colour temperatures are possible, but control over time is complex because all three colours have a different temperature dependence. This is therefore applied less often for lighting purposes.

For LEDs with conversion by a luminescent material, the colour temperature is determined by the choice of the luminescent material.

**Colour rendering**
The CRI or Colour Rendering Index of a light source reflects the quality of the colour rendering of the objects lit by the light source. In order to reach this index, we compare the colour rendering of objects lit by the light source with the colour rendering of the same objects lit by a black reflector (with the same colour temperature).



## Colour quality

Colour quality is determined by colour fidelity (range <0 - 100) on the one hand, and colour gamut (GAI, range 0 - 100) on the other hand. The colour fidelity of a light source – quantified by colour rendering index Ra (CRI – Colour Rendering Index) – reflects the reliability of the colour rendering of an object illuminated by said light source. In order to reach this index, we compare the colour rendering of objects illuminated by the test light source with the colour rendering of the same objects illuminated by a reference light source (black reflector with the same colour temperature).

The colour rendering index of LEDs is comparable to that of fluorescent lamps and varies between 60 and 98.

- For regular lighting applications in warm or neutral white, ETAP uses LEDs with colour rendering of 80 (in accordance with standard NEN-EN 12464-1).
- For battery-operated emergency lighting systems output is more important than colour rendering (minimum colour rendering of 40 is required here). That is why we use highly efficient cold white LEDs in emergency lighting with colour rendering of approximately 70.

In white LEDs the colour rendering index is determined by the composition of the luminescent material (phosphorous).

By way of comparison:

| | |
|---|---|
| Fluorescent: | Ra from 60 to 98 |
| LEDs: | Ra from 60 to 98 |
| Incandescent lamp: | Ra of 100 |
| CDM: | Ra from 80 to 95 |
| Sodium light: | Ra of < 0 |

Colour gamut refers to the colour range that an appliance or light source is able to reproduce and is reflected by the Gamut Area Index (GAI). The greater or wider the gamut, the richer the colour palette and the better the rendering of saturated colours.

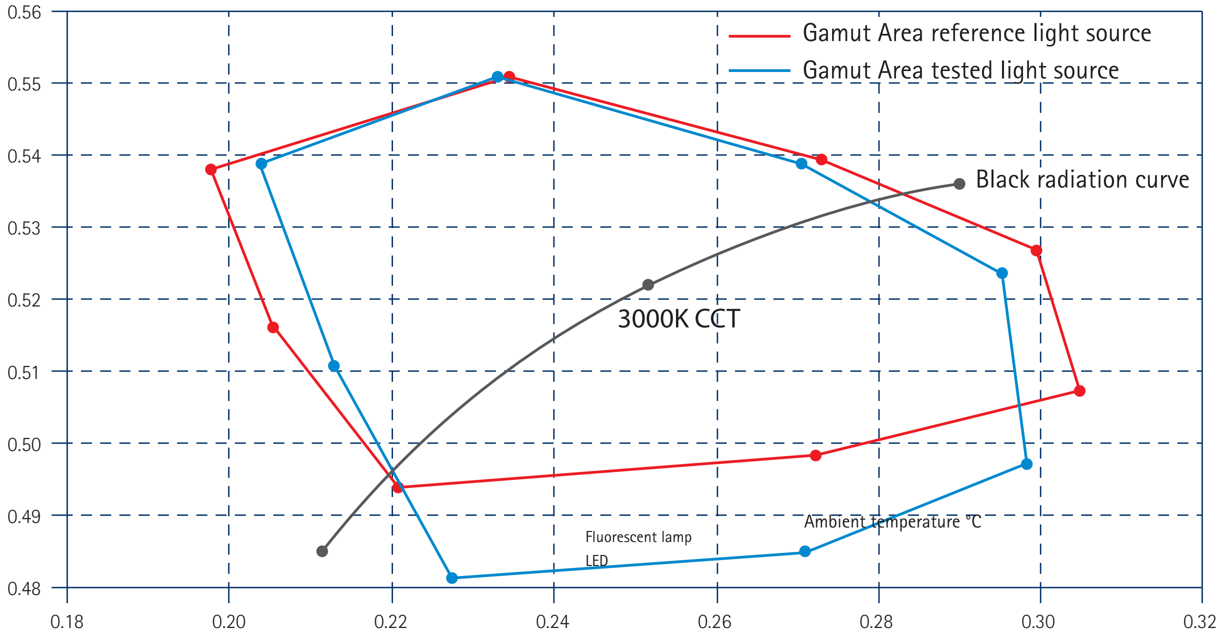



*Fig. 18: Example of a GAI for a vibrant white module (3000 K rosy white light). (Source: Xicato)*

The red line in the above figure reflects the IEC colour coordinates for a reference light source (3000 K) – the blue line the colour coordinates of the test source. Whilst the CRI/Ra is a measure for the average deviation between blue and red points, GAI is the relationship of the surfaces between the blue and red polygons. In this example the GAI is greater than 100, which means that the test source reflects a richer colour palette than the reference light source. Ra is smaller than 100 by definition.

A high CRI does not always guarantee a high gamut. And conversely, a low CRI does not exclude good colour quality – thanks to a high gamut-value.

Recently increasing attention has been paid to the light quality and colour rendering of LED lighting. Especially in retail new trends such as specialty whites are making their appearance. For example, some stores request crisp white lighting (with extra blue as a whitener – e.g., Philips Crisp white), or clothes stores ask for lighting with pink tones (e.g., Xicato vibrant white), for a more acceptable colour quality.

## Advantage 4: Stable performance across wide temperature range

Compared with fluorescent lamps, LEDs are less sensitive to ambient temperature. Whereas the luminous flux in fluorescent lamps drops drastically at ambient temperatures higher or lower than 25°, LEDs exhibit only a gradual decrease at higher ambient temperatures. This is a significant advantage in environments with unusual temperatures (< or > 25°) or subject to temperature variations (e.g. industry).

However, this does not detract from the importance of the thermal design: a well thought-out temperature control is crucial for achieving maximum lifetime and light output (see also chapter 2.4).

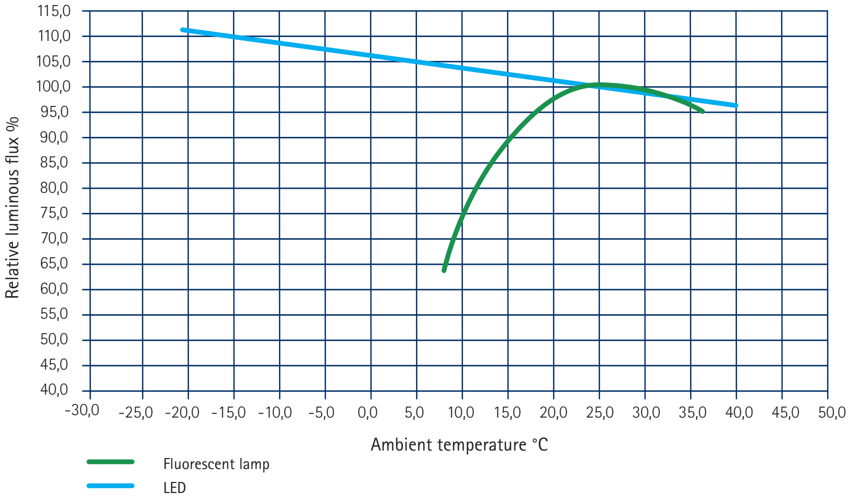



*Fig. 19: Influence of ambient temperature on relative luminous flux*

## Advantage 5: Immediate light efficiency when switched on

Fluorescent lamps do not immediately emit a full luminous flux when they are turned on. LEDs, on the other hand, react immediately to changes in the power supply. After being switched on they immediately reach maximum luminous flux; they are therefore highly suitable for applications that are often switched on/off and the light is often only turned on for short periods of time.

This is also true for lower ambient temperatures, in which they even work better. This advantage is, for example, appreciated in the E1 with LED for deep freeze applications.

In addition, LEDs – contrary to CDM lamps, for example – can also be switched back on without problems when they are still warm and in most cases, frequent switching has no negative impact on lifetime.

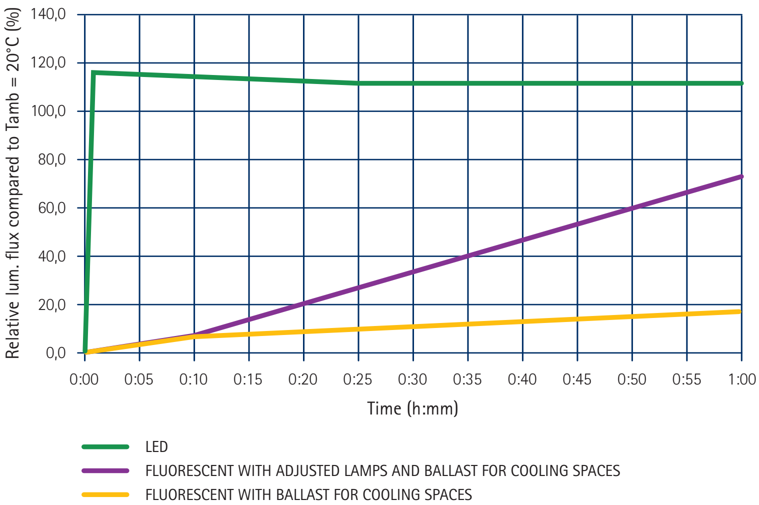



*Fig. 20: Comparison of the start-up behaviour of LED vs fluo at -30 °C*

## Advantage 6: Easily dimmable over a broad range

LEDs can be efficiently dimmed over a broad range (from nearly 0% to 100%) or dynamically controlled, which is possible on the basis of standardised dimming methods such as DALI, 1–10 V or TouchDim.

Dimmer losses in LEDs in the lower dim ranges are comparable to dimmer losses in fluorescent lights with the latest dim ballasts. When fully dimmed the residual power consumption is practically negligible. LEDs are therefore highly suitable for integration into programmed, dynamic environments.

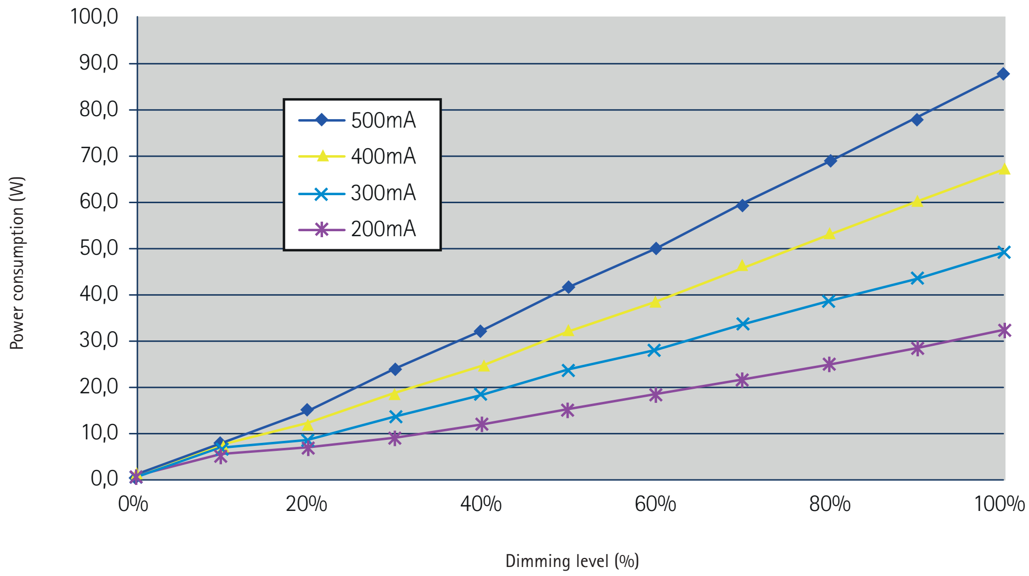



*Fig. 21: Effect of dimming on power consumption*

Output and specific luminous flux typically drop under lower power. For example, downlights with power consumption under 20 W are usually less efficient than 40W luminaires or higher.

## Advantage 7: Environmentally friendly

From LCA* (Life Cycle Analysis studies, which examine the ecological impact of a product from production to recycling and processing) it appears that LEDs, compared to other light sources, will potentially have the smallest ecological footprint in the future. Furthermore they do not contain mercury, which is the case for fluorescent lamps.

* Assessment of Ultra-Efficient Lamps; Navigant Consulting Europe; 5 May 2009.

## Advantage 8: No IR or UV radiation

LEDs do not develop ultraviolet (UV) or infrared (IR) radiation in the light beam*, which makes them highly suitable for environments where such radiation is to be avoided as in museums, stores with foodstuffs or clothing shops.

The LED itself does generate heat, but it is led to the back, away from the object to be lit (we will come back to this later – see Section 2.4). Also the radiated light beam represents energy which is converted into heat as it is absorbed.

* The housing, by contrast, does generate IR radiation (through heat).

## 4. LED MANUFACTURERS

At ETAP we use a number of criteria to select the manufacturers with which we collaborate. The principal criteria are performance, price, documentation (demonstrable data with reference to valid standards), long-term availability (important for continuity in our production of luminaires).

ETAP works together with several suppliers, depending on the platform, whereby the requirements mentioned above is used.

## 5. THE FUTURE OF LEDS

LED technology gradually reaches the maturity phase.

- The specific luminous flux of LEDs is still on the increase. Today they are far ahead of halogen, incandescent and fluorescent lamps in terms of light output. In terms of efficiency and/or specific power LED luminaires leave the most efficient fluorescent solutions in their wake. Broadly, it can be stated that in recent years the price of the same lumen package has dropped by 25%, or that the same price now buys you 10% more specific luminous flux. Currently a limit is nonetheless expected at 200 to 240 lm/W for warm colours.
- New technologies are still being developed to improve colour quality and cost in the long term.
- Colour control has continued to improve, resulting in tighter binning, so that some manufacturers increasingly offer just one bin (3 SDCM). (Further information on binning can be found in Section 2.5)

## 6. OLEDS

OLED stands for organic light-emitting diode. As the name indicates, it involves a variant of the traditional LED. However, whilst LEDs are based on crystalline, inorganic material (e.g., gallium nitride), OLEDs use organic macromolecules based on hydrocarbon compounds to produce light.

*OLEDs in various forms (e.g. Philips Lumiblade)*

**Point vs. surface**

The difference between OLEDs and LEDs not only lies in the material, but also in the mode of operation. Whilst an LED is a typical light point source, OLEDs are used to spread light over a specific surface. In practical terms, the organic light-emitting particles applied in a wafer thin layer onto a substrate made from glass or another transparent material and connected to a cathode and anode. The layer lights up whenever voltage is applied to the cathode and anode. By combining the correct materials, OLEDs are able to generate light in a specific colour.

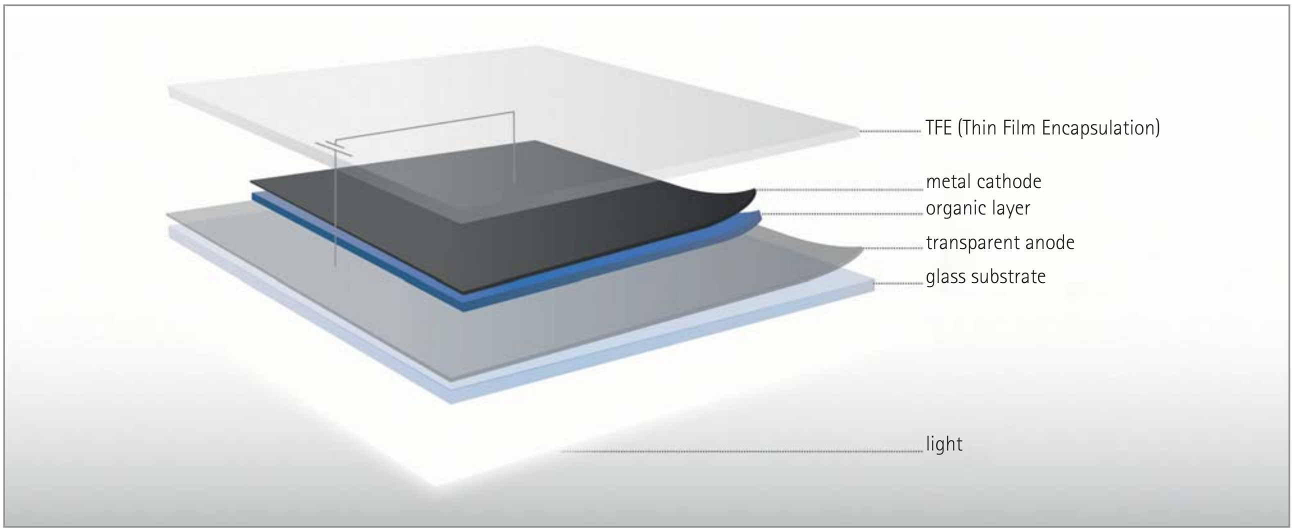



*Fig. 22: OLED structure*

**Complementary to LEDs**

This fundamental difference between LEDs and OLEDs also instantly explains why both technologies will be complementary and will continue to exist side-by-side in the future. OLEDs produce a quiet, diffuse and non-blinding light across a specific surface, whilst LEDs lend themselves perfectly to creating light beams that can be aimed and spread. The fact that OLEDs are a surface light source with perfectly even illumination makes them highly suitable for applications such as emergency lighting. In addition, they also look very promising in general lighting applications, such as light-emitting panels.

**Performance**

Today OLED technology is still being developed. In terms of performance and service life so far they are certainly not in the same league as LEDs. OLEDS achieve light efficiency of 60 lm/W compared to 160 lm/W for LEDs. For signage purposes they are just about as efficient as specific LED products, because by nature they are more suitable for those applications. Just as for LEDs it is expected that the performance of OLEDs will increase considerably due to new developments.



**OLED Roadmap**

| year | 2015 | 2016 | 2018 |
|---|---|---|---|
| Luminous efficacy | 50 lm/W | 90 lm/W | 120 lm/W |
| Life time (L70 @ 3 000 cd/m²) | 20,000 h | 40,000 h | 60,000 h |
| Brightness | 3,000 cd/m² | 4,000 cd/m² | 5,000 cd/m² |
| Lumen output | 10,000 lm/m² | 15,000 lm/m² | 20,000 lm/m² |
| Colour Rendering Index (CRI) | >90 | >92 | >95 |
| Max. dimensions | 150*150 mm | 320*320 mm | 400*400 mm |

*Fig. 23: Current and expected OLED performance (Source: LG)*

The surface that can be illuminated with a single OLED module is still in full development. In televisions the screen consists of several OLED pixels, since there the screen resolution primarily plays a role. In lighting applications, however, we strive to illuminate as large a surface as possible with a single module. The plus points are that we can easily control it and that it does not create a pixellation effect. These days light panels measuring 15 cm x 15 cm are available as standard, in the future sizes up to 1 $m^2$ certainly are among the possibilities.

The presence of organic materials – which age relatively fast and are quite sensitive to air and moisture – results in a fairly limited lifespan. Today 20,000 burning hours are assumed (with 30% decrease in light output, and a continuous control of 3 000 cd/$m^2$). Further development of the materials used, protective layers and production techniques will lead to major improvements in this area.

**Flexible and transparent?**

Today OLEDs are almost exclusively mounted onto glass. Research currently focuses on the options to mount OLEDs onto more flexible materials and thus create mouldable lighting panels. Each surface – smooth, curved or even elastic – then becomes a potential light source. Just think of light-emitting walls, furniture, curtains or clothing.

Another area of research is the development of transparent OLED panels. Currently unlit OLEDs still form a reflective surface. The transparent panels could, for example, act as windows during the day and when darkness falls provide pleasant mood lighting. This makes OLEDS a highly promising lighting technology with nearly endless new areas of application.

*OLEDs as an interactive mirror*

## ETAP introduces OLED technology in emergency lighting

End 2013 ETAP was the first to launch an OLED-based signage luminaire. With their low light levels and homogeneous output, OLEDs are eminently suitable for this purpose.

*K4, signage series with OLED*

# Section 2: Designing LED luminaires

## 1. OPTIONS AND CHALLENGES

LEDs are very small compared to more traditional light sources such as fluorescent lights. In other words, the total light source for a luminaire can be spread over the total surface, which allows for the creation of slimmer luminaires and much more innovative designs.

But when designing LED luminaires we are faced with more than one challenge. We must first select the right LEDs for the intended application. Power, luminous output, temperature behaviour, lifetime, colour temperature and cost are important parameters in this respect. The design and integration of optics (lenses, diffusers, reflectors) ensure the desired light distribution. The heat management of LED luminaires is also critical to performance. And we prefer to combine all of this with a beautiful design.

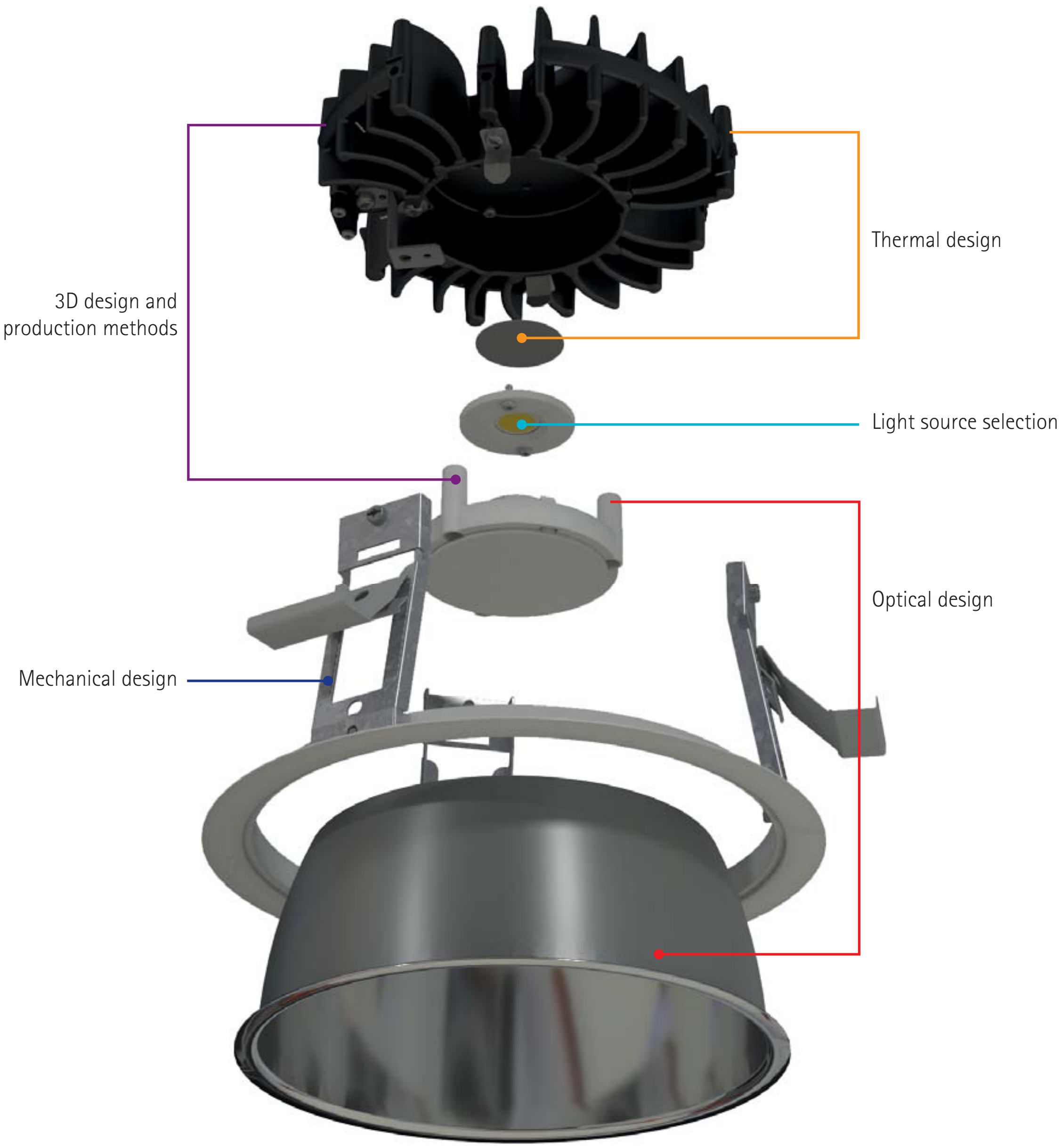


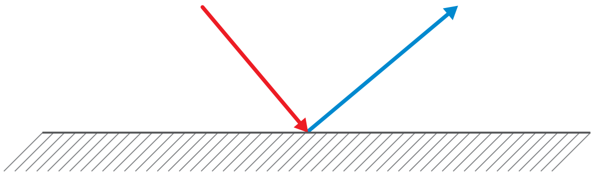

*Fig. 24: D1 downlight design*

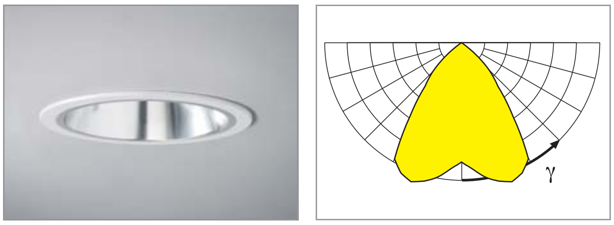
## 2. SUITABLE LIGHT DISTRIBUTION

Most LEDs have a wide light distribution and emit light at an angle from 80 to 140° (full angle). Secondary and tertiary optics (reflectors, refractors and diffusers) can be used to achieve specific light distributions. An appropriate light distribution is important to minimise specific power and hence also energy consumption in any given application.

### a. Reflection

The desired light distribution is created by reflecting the light on a surface.

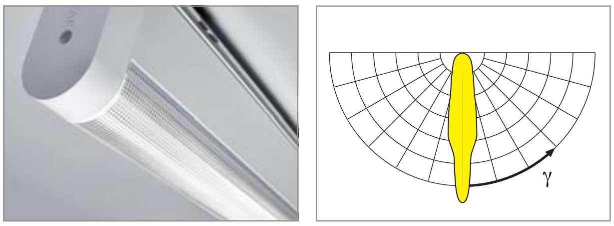




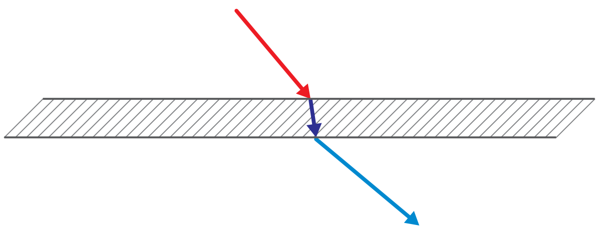

*e.g., D1 led*

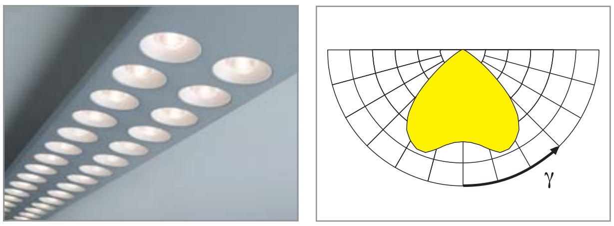
### b. Refraction

The light is sent through a transparent material (e.g., lens) and is bent due to the optical density (refractive index) and the shape of the material surface and subsequently sent in the right direction.

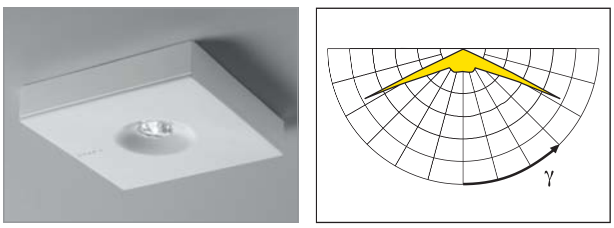



*e.g., E4 with DUAL•LENS technology with narrow-angle lens*






*e.g., R7 with LED+LENS™ technology with wide-angle lenses*

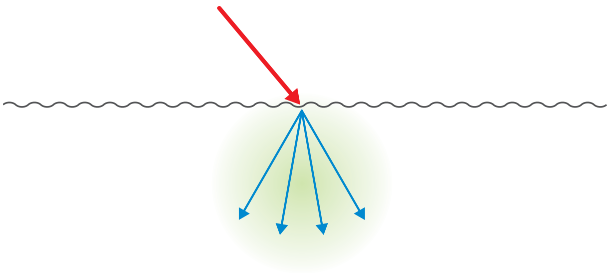


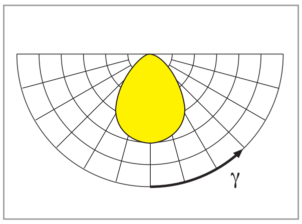

*e.g., K9 anti-panic lighting with extreme wide-angle lens*

## c. Diffusion or multiple deflections

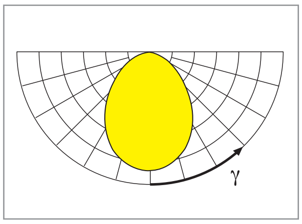
The light is diffused.

*A. On a material surface by means of a surface structure*



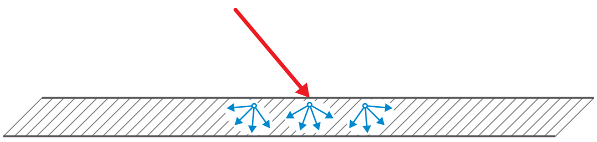


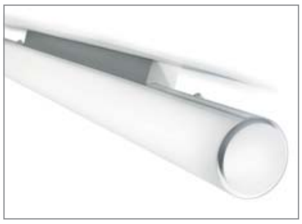

*e.g., U25 with MesoOptics™ foil*

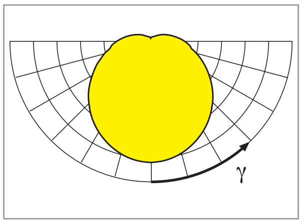



*e.g., US with microprism structure*

*B. In a material volume by means of inclusions, e.g., R8 with HaloOptics® diffuser*








*e.g., R8 with HaloOptics®-diffusor*

## 3. LUMINANCE UNDER CONTROL

With the constant rise in LED performance and maximum power, source luminance also increases rapidly. This luminance can easily reach 10 to 100 million cd/m². The smaller the surface from which the lights emanates, the greater the light source's luminance can become.

A few examples of source luminances:

| | |
|---|---|
| • Linear fluorescent - T8 | 14,000 cd/m² |
| • Linear fluorescent - T5 | 15,000 – 20,000 cd/m² → 17,000 cd/m² (HE) and 20,000 - 33,000 cd/m² (HO) |
| • Compact fluorescent, e.g., 26W | 50,000 cd/m² |
| • Naked LED 3W (100 lm) | 100,000,000 cd/m² |
| • Sunlight | 1,000,000,000 cd/m² (=10x LED!) |

A well thought-out optical design is therefore an absolute necessity in order to diffuse the light of these bright point sources, avoid direct exposure and decrease glare. To do so, we are able to use lenses, reflectors as well as diffusers. A few examples:

- D4 downlights (UGR<19, luminance <1000 cd/m² at 65°):
  - Diffusion of light source across large surfaces in order to limit luminance.
  - Use of lenses with textured surface for the diffusion of peak luminance per light source.
- U2 with LED: the light source is spread over the entire luminaire. The MesoOptics™ diffuser eliminates disturbing luminances and allows for controlled light distribution.

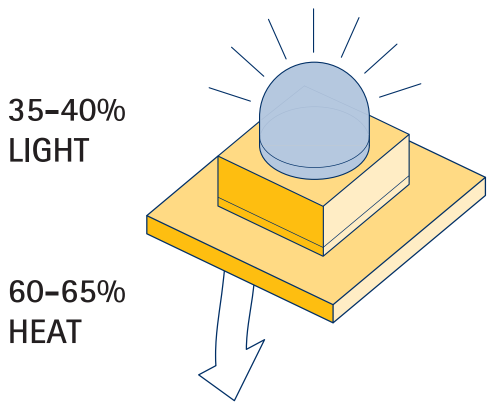
## 4. WELL THOUGHT-OUT THERMAL DESIGN

Temperature management (cooling) is without a doubt the greatest point of particular interest in the development of high-quality LED lighting. Depending on LED performance 35-40% of energy is converted into visible light and 60-65% into heat within the component (dissipation).

By way of comparison: fluorescent lights emit some 25% of converted power as visible light. But the difference resides in the fact that in fluorescent lighting some 40% of energy is also emitted in the form of infrared or heat radiation. The remaining 35% are converted into internal heat and UV.

The luminous output of LEDs drops gradually depending on increasing junction temperature.

At lower temperatures, the luminous output increases: LEDs always work better as their operating temperature drops.



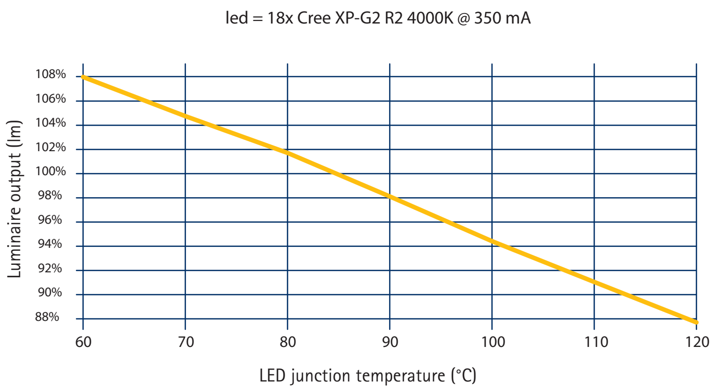




*Fig. 25: Influence of junction temperature on luminaire output (ref. 85°)*

Temperature not only impacts luminous output. Functional lifetime is also affected whenever a critical temperature is exceeded.

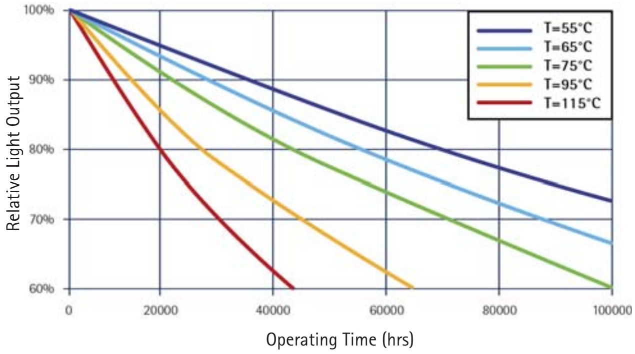
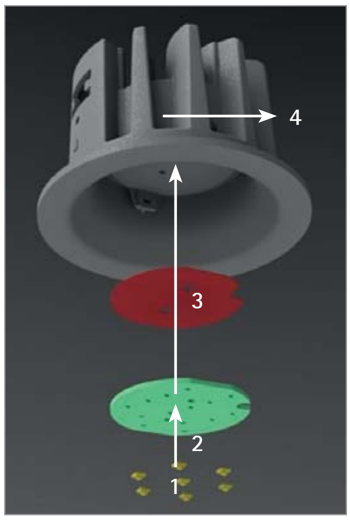



*Fig. 26: Depreciation of the luminous flux over time for different junction temperatures*

Good temperature management is therefore critical. Heat extraction from the LED to the environment takes place in successive steps (through various heat resistances):

- The heat generated by the LEDs is led through the substrate to the soldering point (1, internal in LED).
- From there the heat is spread across the LED circuit board (2).
- A thermal interface (3) or TIM (Thermal Interface Material) ensures optimal heat transfer between PCB and heatsink (4).
- Through convection and radiation the heat is carried off to the environment.




Free flow of air around the luminaire is essential to proper heat emission, which is why the thermal behaviour of an LED appliance will be different for surface-mounted than for recessed luminaires, and for recessed luminaires, sufficient free space around the luminaire must be provided (hence no insulation!). Maintenance of the heatsink (keeping it dustfree) is important as well for a good temperature management.

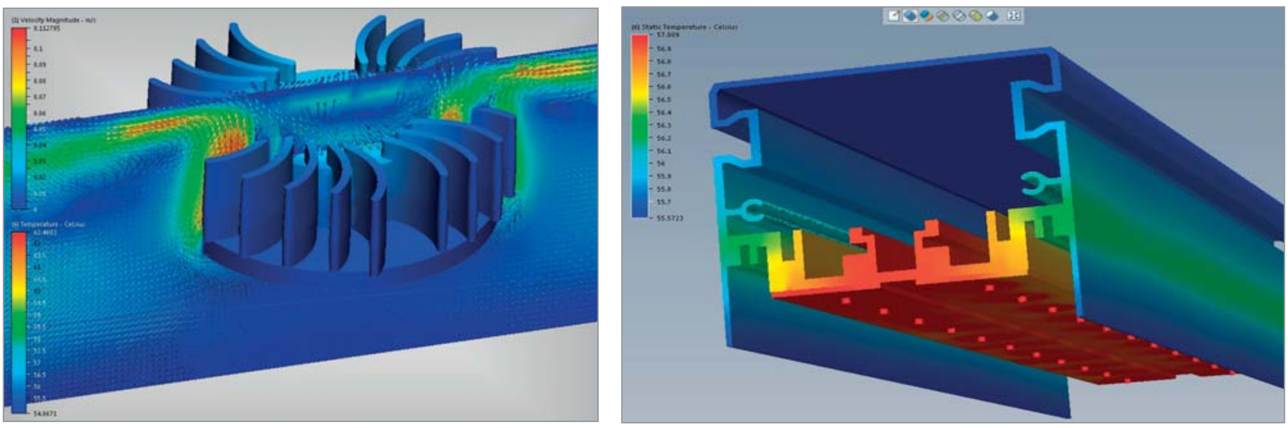


*Fig. 27-28: Thermal design of D1 (left) and E7 (right).*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## 5. BINNING FOR CONSTANT LIGHT QUALITY

During production, LEDs in the same batch or series display various properties, for example with respect to intensity and colour. The use of a mixture of various LEDs in the same luminaire would therefore inevitably lead to various luminous intensity levels and various light colours, which is why we practise 'binning'.

'Binning' is the sorting of the LEDs according to specific criteria such as:

- Colour binning: sorting according to colour coordinates (x, y), centred around individual colour temperatures.
- Flux binning: sorting according to luminous flux, measured in lumen (lm).
- Voltage binning: sorting according to forward voltage, measured in Volt.

By selecting a specific 'colour bin', constant light quality is guaranteed. LEDs in the same bin therefore have the same appearance. Differences in colour bins attract attention when a wall is being uniformly illuminated.

In the study of colour vision, the so-called Mc Adam ellipse (see figure) is used, which is a region on the CIE diagram, which includes all colours indistinguishable to the average human eye from the colour at the centre of the ellipse. LED manufacturers use SDCM (Standard Deviation Colour Matching), whereby 1 SDCM equals 1 MacAdam.

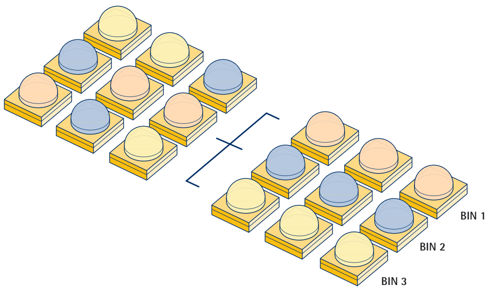



*Fig. 29: The principle of binning*

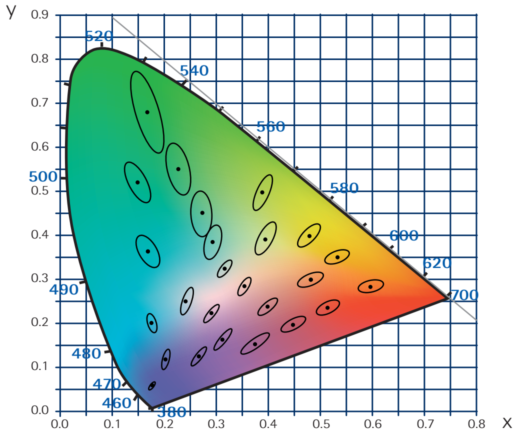



*Fig. 30: Visualisation of MacAdam-ellipses (source: Wikipedia)*

UPDATE

### How does ETAP apply binning to lighting luminaires?

ETAP follows the binning policy of qualified LED manufacturers, who develop said policy in accordance with technical advances, new process management, logistical aspects, etc. The changes do not affect the end user: the amended methods result in a uniform colour temperature. ETAP luminaires (with low-power LEDs, high-power LEDs as well as chip-on-board LEDs) satisfy 3 SDCM.

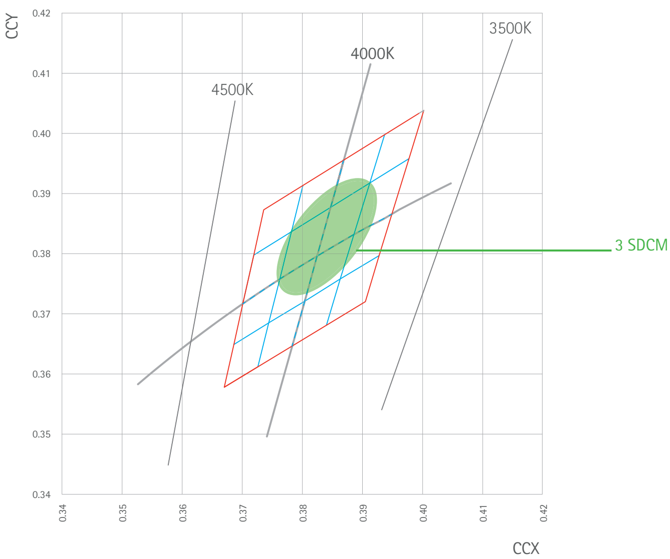



*Fig. 31: Illustration of binning principle*

## 6. ELECTRICAL SAFETY

LEDs work at a low voltage (typically about 3V), therefore it is often thought that electrical safety is not a concern. Currently, lighting solutions with LEDs can run at voltages of 100V or more. As a result, we must take additional measures in order to make the fittings safe to touch.

**LEDs in series increase voltage**

LEDs in lighting luminaires are preferably connected in series where possible. The logical result, however, is that the voltage increases. One of the benefits of LEDs is that they run on low voltage with a difference in voltage of approximately 3V per LED. But if 30 LEDs are connected in series within one luminaire, you already have 90V. There are even LED drivers that can generate an output voltage in excess of 200V. These require further protection electrically.

**Additional insulation needed from 24V**

| AC | DC |
|---|---|
| $V < 25\ V_{RMS}$ ($I_{RMS} < 0{,}7$ mA) | $< 60\ V_{DC}$ ($I_{DC} < 2$ mA) |
| $25\ V_{RMS} < V < 60\ V_{RMS}$ | $< 60\ V_{DC} < V < 120\ V_{DC}$ |
| $60\ V_{RMS} < V < 120\ V_{RMS}$ | |

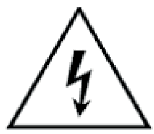
*Fig. 32: According to the international standards IEC 61347 up to 24V (AC) or 60V (DC) there is no risk in touching (green). In LED luminaires with higher output voltage (red) additional safety measures should be taken.*

International standards (IEC 61347) stipulate that for above 24V*, extra measures should be taken to make the luminaires safe. LEDs and other current conductive parts should not be accessible from the outside. The solution must be found so that the LED can only be touched with special tools after opening. Moreover there must be good basic insulation between all touchable conductive parts of the luminaire and all live parts. In practical terms, ETAP provides sufficient air and maintenance space and uses electrically insulated material without affecting the thermal management.

UPDATE

**Light source replaceable or not?**

The new edition of standard EN 60598 determines whether the light source for LED luminaires is:
A. not replaceable (luminaire is to be destroyed to access the light source)
B. replaceable by the user (light source easily and safely replaceable)
C. replaceable by the manufacturer (light source must be protected by a shield with at least two independent fastenings and cannot be dismantled without tools)



Luminaires within this last category C must, as of 2017, come with a high voltage warning on the luminaires.

**The driver insulation grade determines whether further safety measures are required.*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## 7. PUBLISHING THE CORRECT DATA

**Specific luminous flux as criterion**

For years, the efficiency of fluorescent luminaires has been expressed in terms of percentage, an indication of how efficiently the luminaire uses light. But in the LED era, we refer to lumen per Watt, i.e., light output per unit of power consumption. In this context, it is important that the specific efficiency of the full solution be taken into account, of both light source and luminaire.

The efficiency of a fluorescent luminaire is determined by comparing the luminous flux of a luminaire with a naked lamp. An efficiency indication in terms of percentage is highly demonstrable. It shows how efficiently a luminaire deals with a given amount of light. That is why this indication has become the standard for fluorescent solutions. It is also very easy to determine: just measure the luminous flux of a luminaire with lamp and compare it with the luminous flux of the naked lamp.

**Naked LED is no usable reference**

However, in solutions with LEDs something like that is not possible. Firstly, there are many different types of LEDs. In addition measuring conditions between manufacturers are not always comparable. In addition, the measuring conditions of the naked LED do not meet the terms of use. Luminous flux depends on flux density and operating temperature; at 25°C an LED performs much better than when it has been heated in a luminaire, which is why an indication in percentage would be misleading at a minimum.

**Specific luminous efficacy of lamp+luminaire**

The lighting market relies on a different concept. We now no longer look at a luminaire on its own, but at the lamp/luminaire combination. We work with lm/W, based on the amount of energy needed in a luminaire to achieve a certain luminous flux. This might not be as clear as a percentage, but it is more precise. The performance of LED solutions depends on a lot of factors, such as cooling, driver, power density, hot/cold factor (the extent to which the luminous flux declines when temperature rises), etc. The lm/W indication takes this into account: the more favourable these factors, the greater the luminous flux for the same power. At ETAP we constantly aim higher with our LED luminaires. Currently values up to 130 lm/W are achievable affordably.

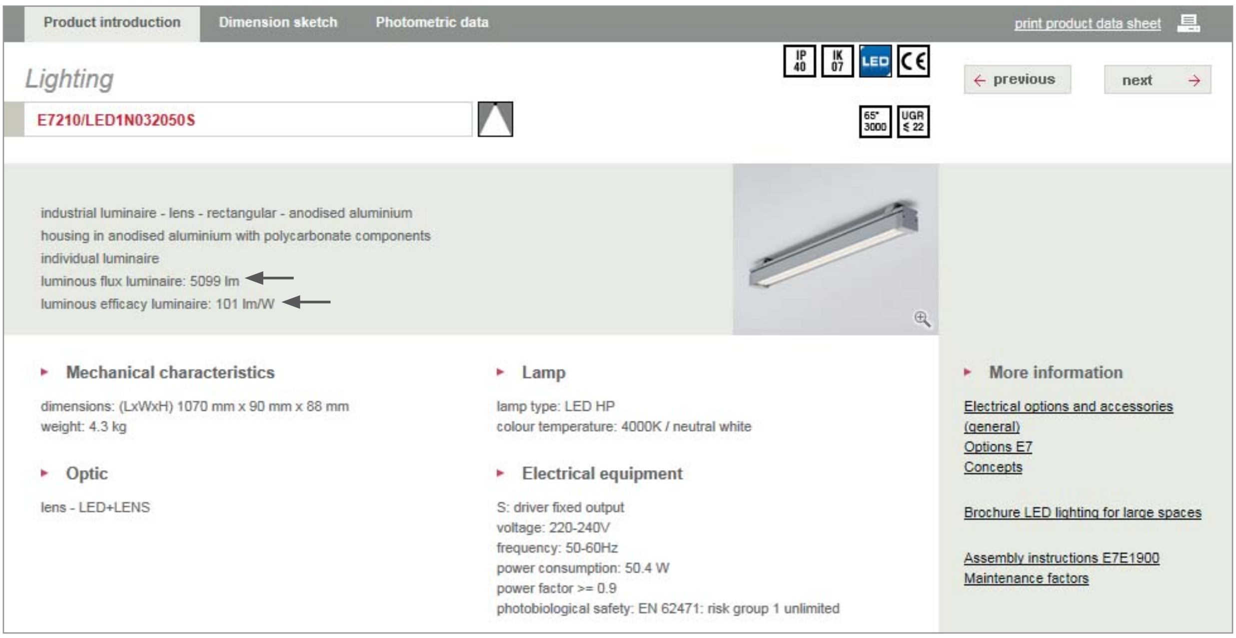


*Fig. 33: Because LED light contains a high peak in the blue spectrum, sufficient attention must be paid to protective measures.*

In addition to luminous efficacy, further details on LEDs can be found on the ETAP website:

- Photobiological safety class
- Colour temperature
- Power Consumption
- Type of driver: dimmable or not
- Power factor
- Maintenance factor

## 8. OBJECTIVE QUALITY INFORMATION

There did not used to be a directive or normative framework in Europe on the publication of quality data of LED luminaires. Manufacturers did publish information, but it was difficult to compare as a consumer. For example: attractive figures could be published for lifespan, without mentioning how these figures had been reached. Or light output and lifespan were published of the LED light source alone, whilst they are largely determined by the optics and the luminaire design. The lack of uniformity was inconvenient for consumers, who often had to compare apples and oranges.

**European regulations**

In 2012, the Federation of National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires in the European Union (CELMA) published a Guide on Quality Criteria for LED Luminaire's performance, in which ETAP took an active part.

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In the meantime the European Commission also has a text of law (European Regulation 1194/2012: Ecodesign for directional lamp, LED luminaires and related equipment) set out below and approved. It details requirements in terms of energy efficiency, functionality and product information. The regulation describes, among others, how performance data and quality features of complete luminaires are to be measured and published, for example:

- Input (W) of the luminaire including supply, luminous flux (lm) and output = output/input (lm/W)
- Overview of luminous intensity (cd) in a polar diagram
- Photometric code that gives an indication of the light quality (colour temperature of light, colour rendering index, chromaticity and luminous flux).
- Maintenance code indicating degradation of the luminous flux over time, specifying expected service life, remaining luminous flux share and failure percentage at that time (see below).
- The ambient temperature (°C) to which the published values apply.

ETAP's documentation complies with these European requirements, as well as international IEC standards, regarding the performance requirements of:

- Luminaires (IEC/62722-1)
- LED luminaires (IEC/62722-2-1)
- LED modules (IEC/62717)

**Does your supplier use a reliable maintenance factor?**

The quoted code for the maintenance factor in de EU regulations refers to a demonstrable, measurable quality feature of a luminaire. In practice that code is usually determined for a period of 6,000 hours or in the best of cases, 12,000 hours. However, in lighting studies we prefer to work with depreciations after 25,000 (which corresponds with 10 years in quite a few standard applications) or 50,000 burning hours. To do so we have to extrapolate. Since the regulation does not provide a judgement in this respect, ETAP applies the American TM21 guideline. ETAP extrapolates its data on the basis of this guideline, in order to be able to take the correct maintenance factor into account for each project based on reliability models. This enables you to be certain that your lighting will perfectly match expectations until the anticipated end of its lifetime. Apart from that the service life of the luminaire is also influenced by the switching of the LEDs (series or parallel) and the aging of the optics. ETAP also takes this into account. Lastly, the European regulation does not impose minimum requirements in terms of degradation of LED luminaires. Yet a high and carefully calculated maintenance factor is of the utmost importance. On the one hand you can be certain of minimum overdimensioning of your lighting installation, on the other hand you are certain that the luminaires still achieve an acceptable lighting level at the end of their lifetime (see 4.1).

UPDATE

| | photometric data | | | LLMF (%) | |
|---|---|---|---|---|---|
| | F (lm) | P (W) | lm/W | 25.000 u. | 50.000 u. |
| U25 | 4047 | 32 | 126 | 99 | 98 |

*Fig. 34: In order to calculate the maintenance factor, ETAP applies the American TM21 guideline combined with reliability models (e.g., U25)*

**ENEC+**

The European quality mark ENEC+ was launched in 2014. Whilst the ENEC certificate relates to the electrical and photobiological safety of electrical appliances, ENEC+ says something about the performance of luminaires. Please note: what is not taken into account in ENEC+ is the degradation and lifespan of LED luminaires: luminous flux is only measured during the initial 1,000 burning hours. The lighting level achieved by your installation after 25,000 or 50,000 burning hours, is information ETAP calculates by means of the above method and which you can find in Appendix 1 or on our website.

## 9. PHOTOBIOLOGICAL SAFETY

The European standard for photo biological safety EN 62471 describes a classification system that indicates whether a lamp or lighting luminaire poses a risk of eye and skin damage. Given the high luminance resulting from many high power LEDs, there is a risk of eye damage. That is why it is important that the photobiological safety be measured correctly and published clearly.

LED light contains almost no light from the ultraviolet or infrared spectrum, and therefore is not dangerous to the skin. It does however provide a high peak in the blue spectrum which, when looking into a bright light source (for a long period of time), may result in irreversible damage to the retina, the so-called the Blue Light Hazard. (BLH)

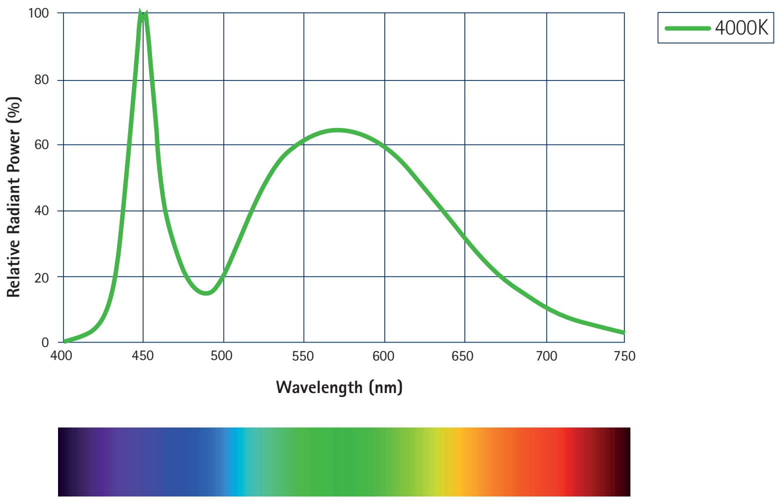



*Fig. 35: Because LED light contains a high peak in the blue spectrum, sufficient attention must be paid to protective measures.*

## Four risk groups

Whether the risk is real, depends on several factors: capacity of the LED, colour temperature, but also light distribution and distance to the luminaire play an important role.

To allow users to estimate the risk, the standard EN 62471 determines that lamps and luminaries must be divided into four risk groups. For the Blue Light Hazard, those groups are defined as follows:

- Risk group 0 ("exempt" group): this means that there is no danger, even with unlimited viewing of the light source.
- Risk group 1: The risk is limited, no more than 10,000 seconds of viewing is allowed (just under 3 hours).
- Risk group 2: up to 100 seconds of viewing is allowed.
- Risk group 3: up to 0.25 seconds of viewing is allowed. This is shorter than the natural aversion reflex of the eye.

Since EN 62471 is a theoretical classification defined on the basis of a fixed viewing distance, in addition, a practice guideline has been developed (IEC/TR 62778), which will replace the current standard EN62471 as of 2016. The risk of BLH in fact also depends on the viewing distance (distance between eye and LED). Normally, one does not look into a luminaire from a short distance, although short viewing distances actually do occur, for example in technical maintenance work. IEC/TR 62778 describes within which distances a given lighting luminaire belongs to a specific BLH risk group (so-called limit distances).

Some examples:

- Diffusers belong to risk group 0 (RG 0), regardless of the viewing distance, e.g. Kardó, R8, U2.
- Downlights and LED+LENS™ luminaires belong to RG 1, regardless of the viewing distance.
- For the light source in Figure 36, RG 1/RG 2 applies with a limit distance x cm, which means that the light source belongs to RG 2 for viewing distances under x cm.

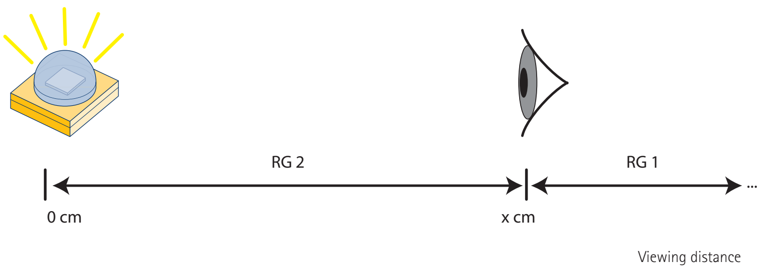
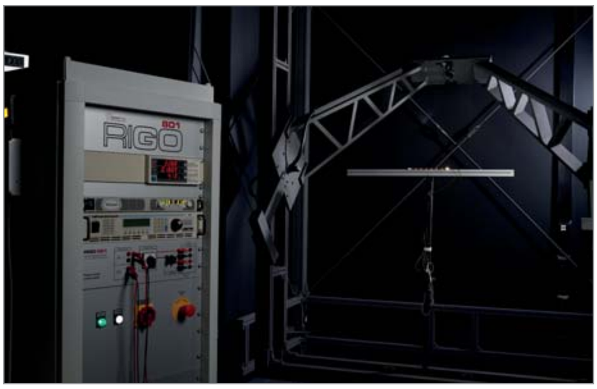



*Fig. 36: Illustration of limit distances*

The extent to which protective measures are required depends on the application. If light sources have a limit distance RG 1/RG 2, this must be specified as such, together with a warning not to look directly into the light source.

Today's bare white LEDs (used in general lighting) in the worst case belong to group 2, never to group 3. In most luminaires there is a lens or diffuser behind those LEDs that optically magnify the image of the source, thereby reducing the peak luminances. This will in most cases result in lower risk class.




*ETAP has the proper instruments to carry out measurements.*

## Measure correctly, publish clearly

To which group a luminaire belongs is determined according to a specific measurement procedure, using specialized instruments (spectrometer). ETAP has the proper setup and instruments to carry out measurements in-house. This means that ETAP can carefully screen all luminaires for photobiological safety. The solution's eventual risk group will be published on the website and in the product documentation.

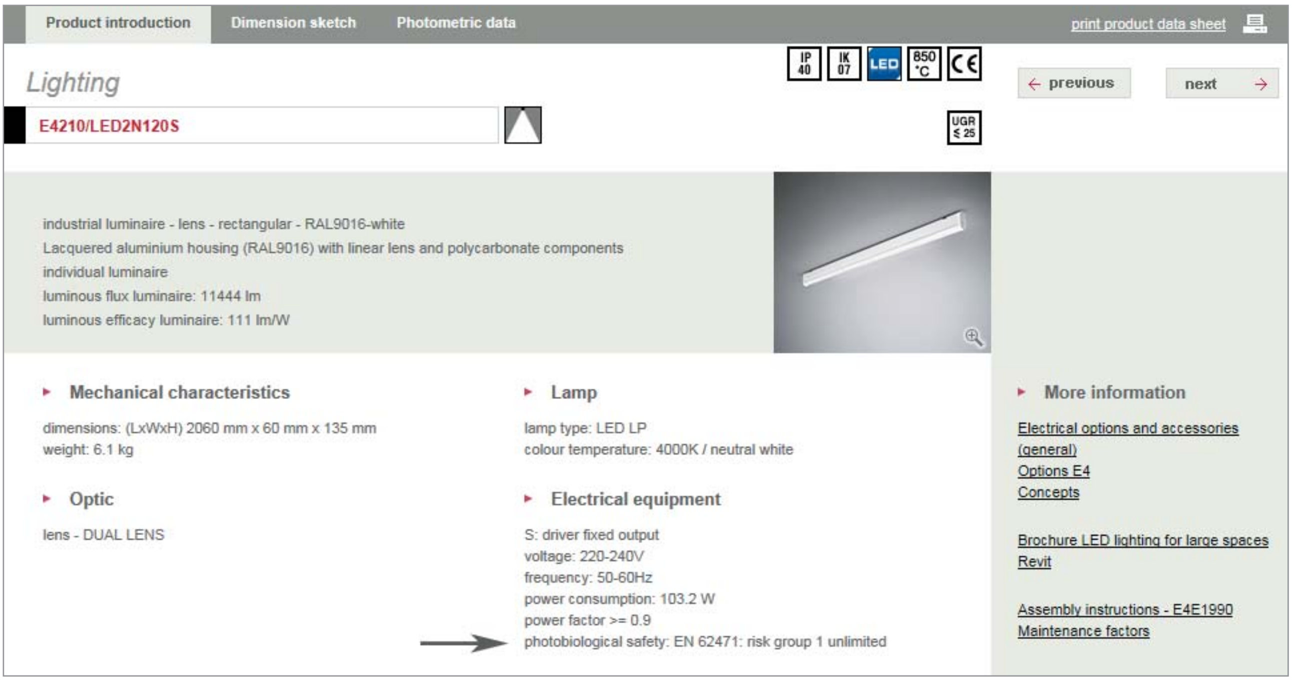



*Fig. 37: You can find exact information about the photo biological safety class of an ETAP luminaire in the product sheet on our website (screenshot website, status October 2015).*

UPDATE

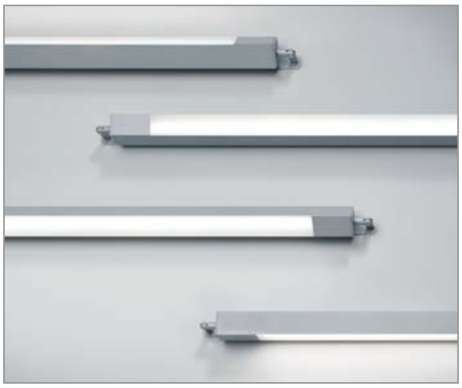
## 10. LEDTUBES

With luminaires specifically designed for this purpose, LED lamps can also offer numerous benefits. However, if you just replace fluorescent lamps in existing luminaires with LED lamps, quality, comfort and sometimes even safety might suffer.

**The EU watches over safe LED tubes**

Via the Rapid Alert System, the European Union has blocked sales of various LED tubes (see website of the European Commission http://ec.europa.eu) because they are not in accordance with the 2006/95/EC Low Voltage Directive and the EN 60598 standard for lighting luminaires. In these products there is a risk, among other things, of electric shock during installation as some external components can become electrically charged.

**Advantages of LED tubes**



LED tubes have numerous practical advantages: they not only have a low energy consumption and a long service life, but are also easy to maintain. If defective the user can replace them (see 6. Electrical safety), without danger of shock. There are also LED tubes in a fully sealed housing, suitable for use in chemical environments. LED tubes in reflector luminaires allow air to be extracted over the reflector, thereby creating a self-cleaning effect.

**Internal or external driver?**

LED tubes can have an internal or external driver. An external driver allows you to dim the lamps and to easily replace them, if necessary.

**Responsible use of LED tubes**

It is important to know that you cannot just replace fluorescent lamps with LED tubes. Often the wiring has to be updated, or luminaire components must be exchanged or bypassed. This cancels out the original luminaire manufacturer's responsibility, but the light quality can also deteriorate as a result: each luminaire is designed for a specific light output and a specific light distribution. By switching to LED tubes without further ado, you will potentially get lower lighting levels, poorer constancy, glare, in short loss of comfort.

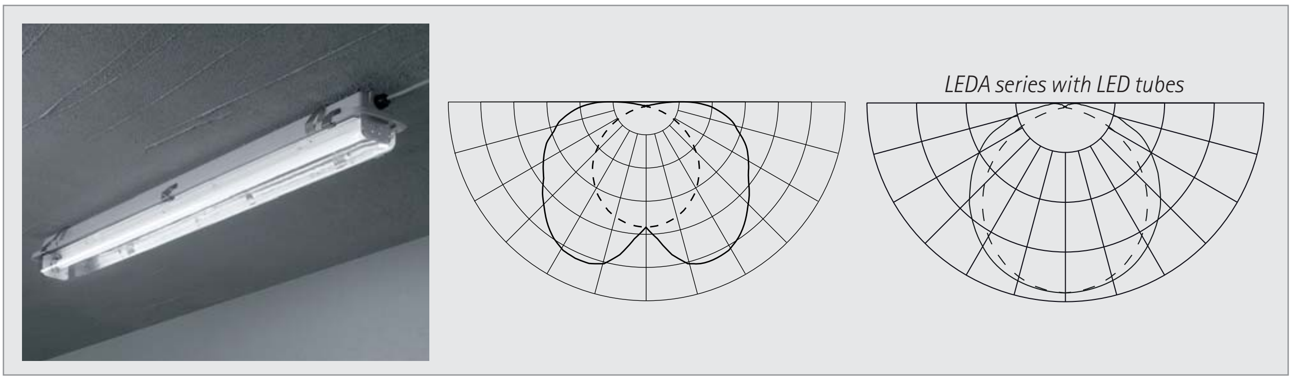



*Fig. 38: While an E12/136HFW (with a 1 x 36W-fluorescent lamp) achieves a luminous flux of 3350 lm, and an efficacy of 72 lm/W, the same device with LED-tube achieves, respectively, only 1340 lm and 61 lm/W. Also, the light distribution with a LED tube (right) is different than the one with fluorescent lamp (middle).*

But it could be different: if you replace the full internal structure (lamp + reflector) by suitable optics, you can still easily switch to LEDs with existing fluorescent lighting. For example, in the E1 luminaires for high protection factor you can easily replace the lamp and reflector by a renovation module, with LED tube, and continue to use your old luminaires. The result: greater efficiency, significantly less (or no) lamp replacement and unchanged easy comfort.

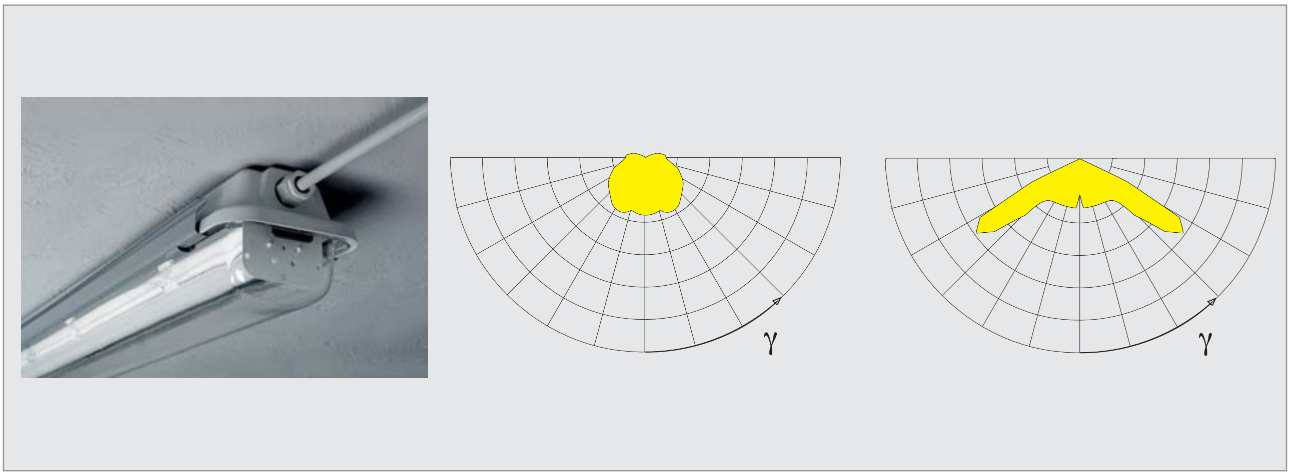



*Fig. 39: If the lighting module (lamps and reflector) on a wide-angle E1 with 2 x 58W lamps, is replaced by an LED module with adapted reflector and LED tubes, you will achieve nearly the same luminous flux (6740 instead of 6700 lm), whilst efficiency increases from 90 lm/W to 120 lm/W. The light distribution of the LED version (right) is also more marked than in the fluorescent version (middle).*

# Section 3: Drivers for LED luminaires

## 1. QUALITY CRITERIA FOR DRIVERS

The driver is one of the most critical components in LED solutions. The quality of LED luminaires not only depends on the LED light source and optical design, but also on the efficiency and reliability of the driver. A good LED driver must meet seven quality requirements:

**Lifetime.** The driver must at least have the same assumed lifespan as the LEDs.

**Efficiency.** One of the success factors of LEDs is energy efficiency. Therefore the conversion of mains voltage into current must be as efficient as possible. A good LED driver has an efficiency of at least 85%.

**Power factor.** The power factor is a technical indicator of the driver that shows how close the current of the waveform approximates the sinusoidal reference of the voltage. The power factor (λ) is composed of two parts: the shift between voltage and current (cos φ) and the distortion of the current (harmonics or the Total Harmonic Distortion). The smaller the shift and distortion of the waveform, the fewer losses and pollution on the distribution network of the energy supplier. In ETAP LED drivers we exclusively work with a power factor in excess of 0.9.

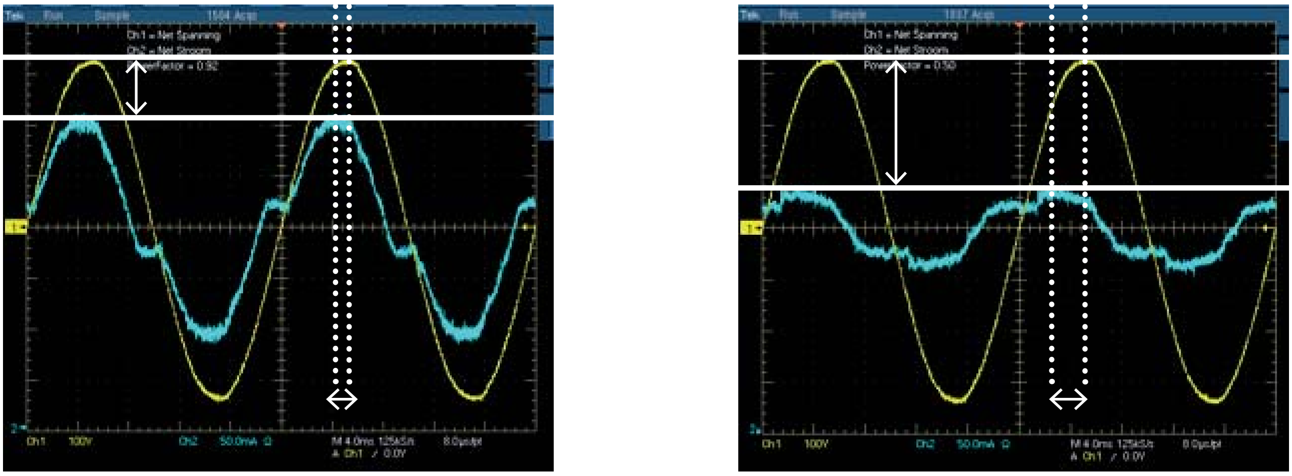


*Fig. 40: For drivers with a high power factor (left), the waveform of the current (blue) shows little distortion and shifting compared to the voltage (yellow). This is the case, however for supplies with a low power factor (right).*

**Electromagnetic compatibility (EMC).** The driver should minimise electromagnetic interference in its surrounding area and, simultaneously, be influenced as little as possible by electromagnetic interference from the surrounding area. Therefore proper electromagnetic compatibility is crucial.

**Switching current (Inrush current)**. When an LED driver is put under power there will be a high peak current on the net for a short period of time (a fraction of a millisecond), because at the start condensers are being charged. In drivers with low switching current, the circuit breakers are not deactivated when a number of luminaires are turned on.

**Waveform current:** A good quality output current prevents intensity fluctuations, so that no flicker or stroboscopic effects will occur.

**Mains voltage filtering.** Pollution of the electricity grid may cause low-frequency light flicker (+/- 50 Hz), among others. The rapid switching capability of LEDs makes them highly visible, which is perceived as highly disturbing. A good LED driver ensures that the pollution of the electricity grid does not affect the output current, so that the luminous flux remains stable. Recently a new standard was published, which describes the measuring process to quantify light fluctuations (IEC/TR61 547-1 Ed. 1: an objective voltage fluctuation immunity test method).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*ETAP testing labs*

**Technical fact sheets**

Drivers are therefore crucial components in all LED solutions. High-quality drivers can be recognised by requesting the technical fact sheets from the manufacturer to check if the above quality requirements are met. ETAP always provides quality LED drivers, perfectly adapted to the solution and thoroughly tested in our labs.

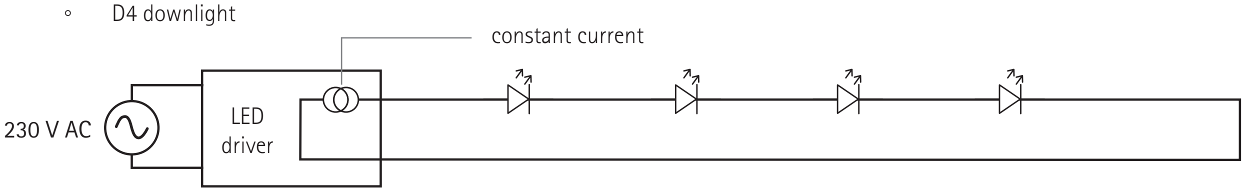
## 2. CURRENT VS VOLTAGE SOURCES

LEDs are current-controlled components. The current is directly responsible for the luminous output and must therefore be carefully adjusted. Two control methods are used:

- **Constant current sources**

  Directly convert mains voltage into constant current. This method yields the highest efficiency and is the most cost-effective method. The disadvantage is that modules with a constant current source can only be connected in series, which is more difficult in terms of installation. In addition, for higher levels the required output voltage adds up quickly (>100 V).

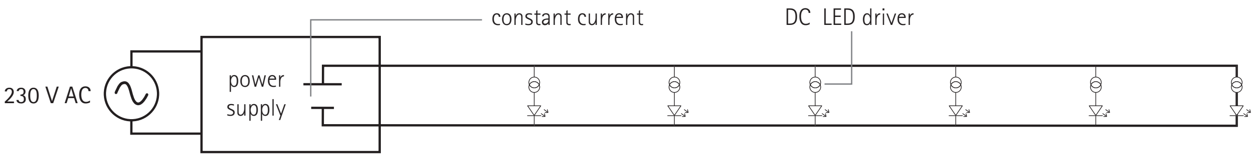
  Examples:
  - Flare spot 500 mA, etc.
  - D4 downlight




- **Constant voltage sources**

  Power supplies that convert mains voltage into carefully controlled voltage. When they are used with LEDs or LED modules, these supplies must always be fitted with a current limiter (e.g., a resistance) or a DC LED driver that converts direct voltage into constant current. The major advantage of voltage sources is that several modules can be easily connected in parallel.

  Example:
  - Flare spot 24 V (DC LED driver integrated in the cable)
  - Distributed DC system, e.g., PoE (Power over Ethernet)



**Also for dimmable luminaires**

The driver should not only be reliable and efficient, it must also have the flexibility to be used in any modern lighting installation. In many cases the level of lighting must be adjustable, for example through a light control system such as ELS or an external dimmer. Note: it is important that the efficiency and the power factor remain the same when using a dimmer.

The maximum achievable efficiency for a driver is determined by the nominal power for which the driver was designed (see Figure 41). For drivers with a nominal power <25W maximum efficiency will never be higher than 80-85%. For drivers with a power greater than approx. 35W maximum efficiencies of 90% and higher can be achieved.

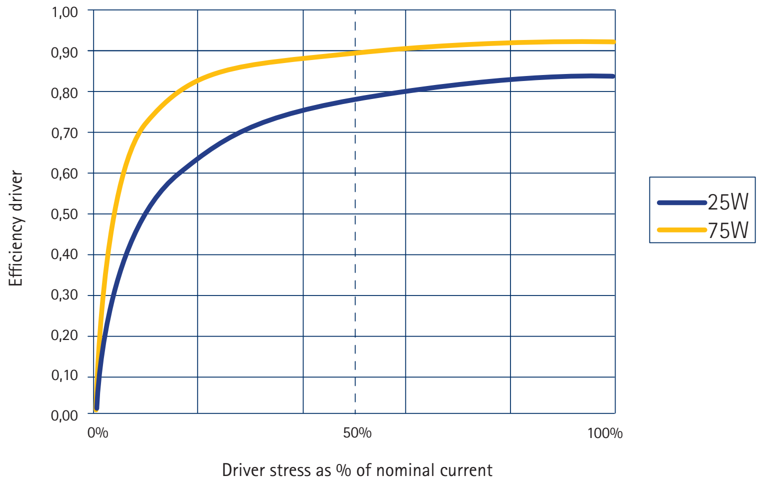



*Fig. 41: Impact of driver stress on efficiency, for a low power driver (blue) and high power driver (yellow)*

The above graphic shows that the actual efficiency of a driver also depends on the load. For a quality driver the efficiency will remain fairly constant to a minimum load of 50-60%. For lower loads the efficiency decreases significantly. That is why it is important to gear LED module and driver to each other, so that the driver always runs in its optimal operating range.

In practice there are two dimming techniques: by reducing the current level (AM or Amplitude Modulation) or reducing the current into pulses of increasingly shorter duration (PMW or Pulse Width Modulation). Both applications have their pros and cons. Our specialists will be happy to help with concrete advice.

All known dimming systems can in theory also be applied to LED lighting:

- DALI
- 1-10V (applied less frequently in LED lighting)
- TouchDim
- DMX (applied less often to lighting, primarily used in the theatre)

## 1. DEPRECIATION AND MAINTENANCE FACTOR

A correctly calculated maintenance factor represents the foundation for an accurately designed lighting installation. A maintenance factor that does not take sufficient account of the specific properties of LEDs, often results in inaccurate lighting studies and calculations.

**Why use a "maintenance factor"?**
The lighting level on the work surface decreases over the lifespan of a lighting installation. The lamps' light output decreases, lamps break and luminaires get soiled with dust and other dirt. The space itself also gets soiled – a recently painted wall, for example, will better reflect the light. That is why in the calculation of an installation, a maintenance factor is applied that takes into account the decrease of the luminous flux (see box text). In this way you can rest assured that the installation will continue to satisfy the postulated lighting level after 5 or 10 years.

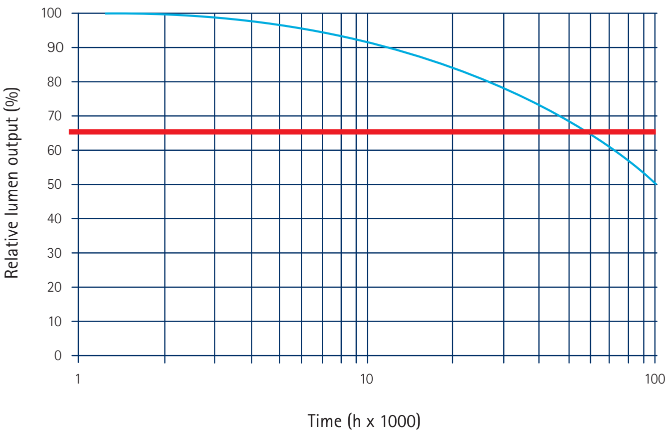
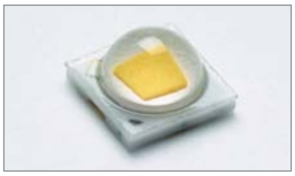



*Fig. 42: Depreciation of the luminous flux over time*

The Maintenance Factor (MF) consists of four parameters

**MF = LLMF x LSF x LMF x RMF**

**LLMF: Lamp Lumen Maintenance Factor**
Decrease in the lamp's luminous flux

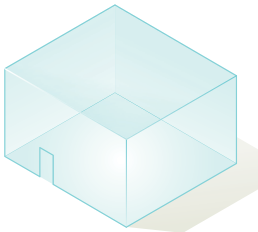


**LSF: Lamp Survival Factor**
Frequency of lamp defects without immediate replacement


**LMF: Luminaire Maintenance Factor**
Decline in luminaires' output due to pollution



**RMF: Room Maintenance Factor**
Space pollution



**Clear rules for fluorescent lighting**

For traditional light sources such as fluorescent lamps clear rules and international standards exist to calculate an installation's maintenance factor. Typically four aspects are taken into account: decrease in luminous flux produced by the lamp, frequency of lamp defects, soiling of luminaire and soiling of the space itself. For fluorescent lighting there is a general consensus about the calculation of the maintenance factor. Depreciation and service life of the lamps have been proven in practice and differ little or not at all between manufacturers. In addition, the luminaire's design has no impact on the lamp's depreciation and it is assumed that the lamps are replaced regularly, so that there is generally little discussion about the maintenance factor of fluorescent luminaires.

**LEDs are different**

This is not the case for LEDs, however, where the maintenance factor depends on a lot more factors. It starts with the choice of LEDs. Today there still is a major quality difference between manufacturers and the type of LED – low or high power – is also decisive in terms of maintenance of luminous flux and lifespan. It is furthermore a fairly recent technology, which is evolving very rapidly. Due to a lack of the necessary knowledge and information today the majority of LED and lighting manufacturers use a LLMF of 70% after 50,000 hours for the sake of convenience, which means that they assume that the LEDs only achieve 70% of their initial light output after 50,000 burning hours, regardless of the quality of the LEDs.

Contrary to fluorescent lighting, the luminaire design also plays a major role. The light output and lifespan of LEDs is highly dependent on their working temperature. The better they are cooled, the lower the depreciation and the longer they will last. Heat dissipation in the luminaire is therefore also critical. However, luminaire design today is seldom taken into account when determining the maintenance factor. In practice each LED luminaire has its own maintenance factor, which makes it impossible to determine a generic value applicable to all fittings.

*In installations with fluorescent lamps, the lamps need to be replaced on a regular basis (blue curve). For LEDs, lamp replacement is no longer needed, but quality of the LEDs plays a major role: Whilst the generally used LLMF is close to 70% (yellow curve), for LEDs in a U7 luminaire, an LLMF of 97% applies (green curve).*

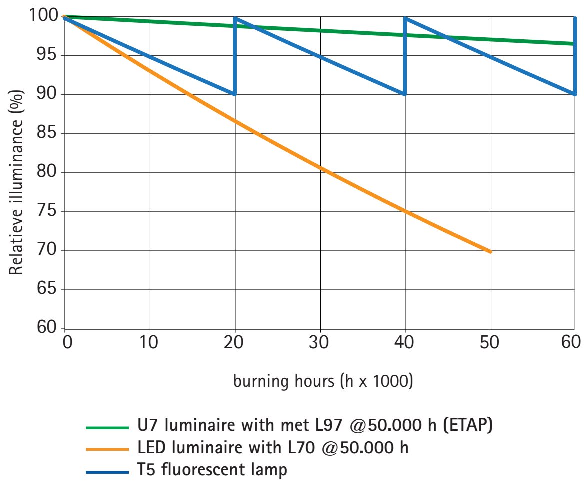


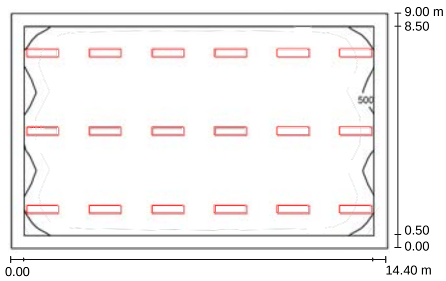

*Fig. 43: LLMF of LED luminaires compared to fluorescent lighting.*

**Major impact on your installation**

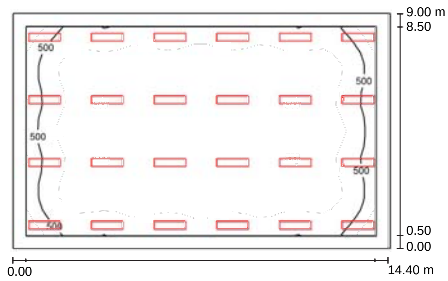
Inaccurate calculations can in practice have major consequences. When the maintenance factor is assessed too optimistically, the installation will no longer satisfy the desired lighting level after a few short years. Conversely, too pessimistic a maintenance factor will lead to an over-dimensioned lighting installation, with too many luminaires and exaggeratedly high installed power, which drive up purchase price and power consumption.

e.g., Impact of the maintenance factor on a lighting study with U7 luminaires in an office space measuring 9 x 14.4 m:

LLMF 97% after 50,000 h (maintenance factor 87%)




LLMF 70% after 50,000 h (maintenance factor 63%)




According to the lighting study with correctly calculated maintenance factor, we need 18 U7 luminaires and an installed power of 0.86W/m²/100 lx (left) for this space The use of the general maintenance factor (right) would lead to an overdimensioned installation: 24 U7 luminaires and an installed power of 1.25W/m²/100 lx.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**High maintenance factor thanks to a clever design**

The maintenance factors ETAP uses in its illumination studies are carefully determined in accordance with international standards. In practice, we find that the ETAP maintenance factors are usually much higher than the value generally applied. That's because we focus on two specific items. Firstly, in our luminaires we always use high-quality (mainly ceramic) LEDs from manufacturers that publish concrete and verifiable data about the light output and service life of their LEDs. In practice this takes place on the basis of the LM80 and TM21 standards, validated by the Illuminating Engineering Society (IES), an international authority on the subject, which provides us with an objective assessment criterion for the performance of the LEDs.

Secondly, we pay close attention to the heat management of our LED luminaires and take this into account. In our labs we have the right infrastructure to channel the junction temperature between the PCB and the LED. In this way we know the working temperature of the LED and we are able to assess more accurately the effective depreciation and life expectancy of the LEDs. We then include them in the calculation of the maintenance factor in our illumination studies.

*We carry out several tests (e.g., endurance tests and light measurements) in our labs in order to carefully determine the photometric data and effective degradation of our LED luminaires.*

UPDATE

**U7 and UM2 remain at high level in independent study**

A recent study by Laborelec, the independent ENGIE research centre (formerly GDF Suez), confirms that our attention for quality and intelligent lighting design bears fruit. In a comparative study of LED lighting for offices, Laborelec tested six luminaires from several suppliers on the Belgian market, among which ETAP's U7 and UM2. Both recessed luminaires won over the panel with maximum efficiency and minimum obsolescence.

Obsolescence was determined according to two methods: Accelerated obsolescence in a climate-controlled room at 45° after 12,000 burning hours (UM2 and U7) and actual obsolescence at room temperature (UM2) after 2,000 burning hours. Both measuring methods confirm that whilst in the other participating luminaires the specific luminous flux drops considerably, the values remained absolutely stable for ETAP, even after respectively 2,000 burning and 12,000 burning hours.

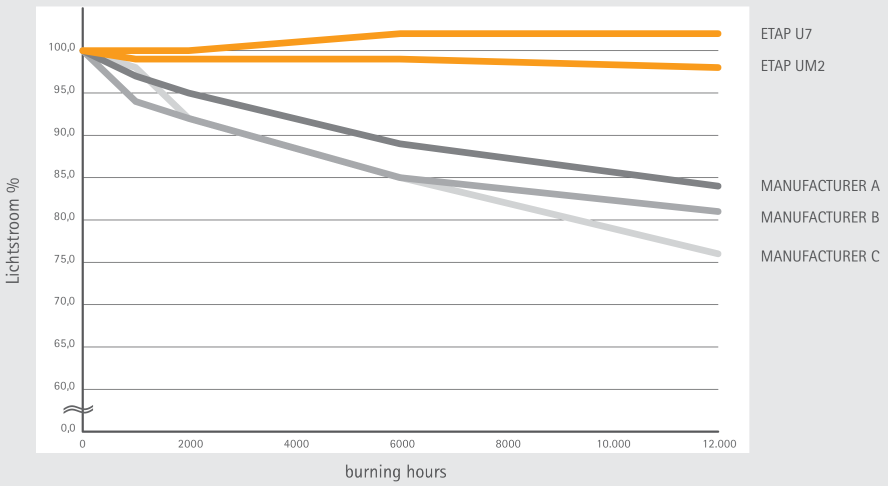



*Fig. 44: Lumen maintenance (LLMF) after 12,000 hours sped up obsolescence*

**Towards a correct calculation**

ETAP provides a table in which you can find the correct maintenance factor for all ETAP LED luminaires, in accordance with the postulated environment and user period. This way, we provide our customers with a reliable illumination study, as well as the certainty that the installation will perform as required.

*An example:*

In a lighting study with U7 in an office environment, the maintenance factor is calculated as follows: 99% (LLMF or lamp maintenance factor) x 1 (lamp failure in LED luminaires is nearly non-existent, and therefore has no influence) x 0,94 (soiling of room) x 0,95 (maintenance factor for closed luminaire) = 88%. This means that after 25,000 hours, 88% of the luminous flux remains. After 50,000 hours 87% of the luminous flux remains, which is significantly higher than the standard 70% after 50,000.

*U7 luminaires in an office environment have a maintenance factor of 87% after 50,000 burning hours (see table).*

| LED type | LED luminaire | 25kh | 50kh | LLMF (%) | |
|---|---|---|---|---|---|
| | | | | 25kh | 50kh |
| High Power | U7 | 88 | 87 | 99 | 97 |

*Fig. 45: Extract from table with maintenance factors and LLMF of U7 for 25,000 and 50,000 burning hours (status mid-2015)*

The complete table of maintenance factors is given in annex 1, or in the product data sheets on our website.

## 2. LIFETIME OF LED LUMINAIRES

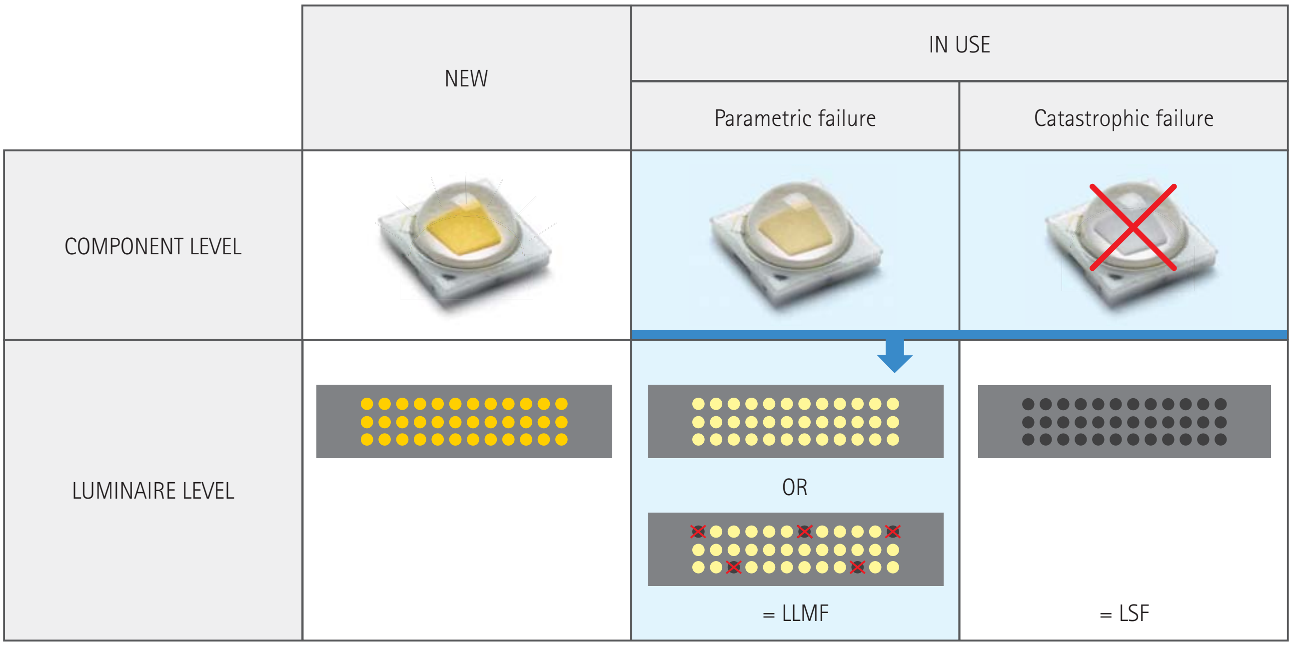
The useful lifetime of LED luminaires is no stand-alone datum, but is always combined with a concrete scenario or installation and consequently also with the maintenance factor. If we look at the maintenance factor formula (Maintenance Factor – MF, se text box on p. 35), the lifetime element is in the last parameter, LLMF.

**LLMF as point of departure**

The figure that reflects the drop in luminous flux of the light source (LLMF) takes into account failing LEDs, and deterioration of the light output over time. How do we determine this LLMF? We distinguish between the service life of LEDs at the component level and at the luminaire level.

At the component level we take into account the gradual deterioration of the luminous flux of the LEDs (parametric failure or B-lifetime), and the potential breakdown of LEDs (catastrophic failure or C-lifetime).

At the luminaire level the complete failure of a luminaire is not relevant (see Luminaire Survival Factor). The LLMF corresponds with the B-lifetime at the luminaire level and hence takes on board the parametric as well as catastrophic failure of the individual LEDs in the luminaires.



**Relevant and reliable data**

In order to achieve an accurate, reliable LLMF for our luminaires, we proceed as follows:

- We determine the parametric failure at the component level in accordance with objective LM80/TM21.
- We are unable to calculate the catastrophic failure, but prefer to collaborate with manufacturers who make accurate data available. Whenever no measurement data are offered, we depend on electronic reliability models (MIL-HBK-217F).

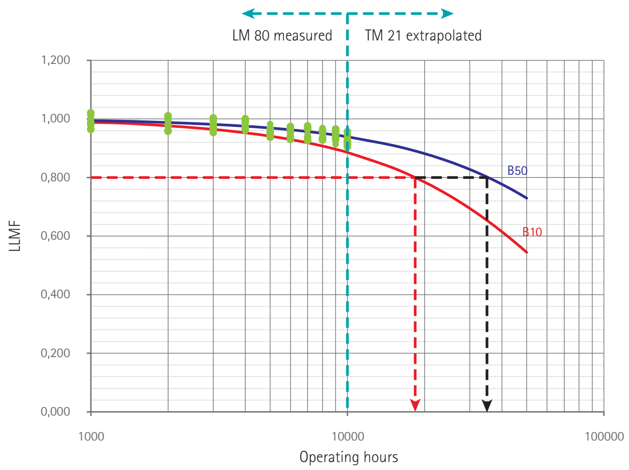



*Fig. 46: LLMF is determined in accordance to the LM80/TM21-method recommended by IES.*

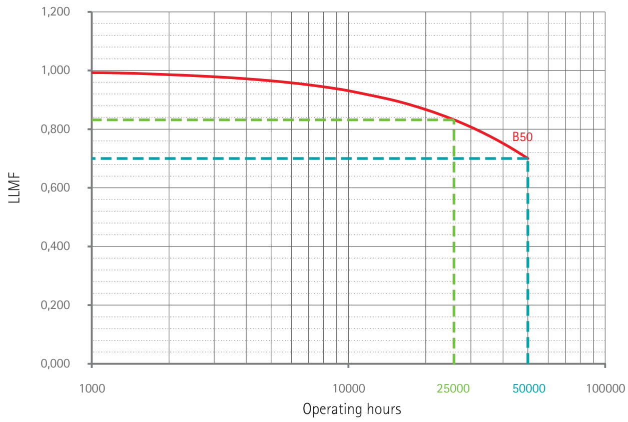



*Fig. 47: ETAP provides the LLMF after 25,000 and 50,000 burning hours for all its LED luminaires.*

You will find both the LLMF and the maintenance factor for our LED luminaires on our website. We always publish both values for two periods: 25,000 or 50,000 burning hours. In this way you will know how much light your luminaires will give off after a period of use relevant to you.

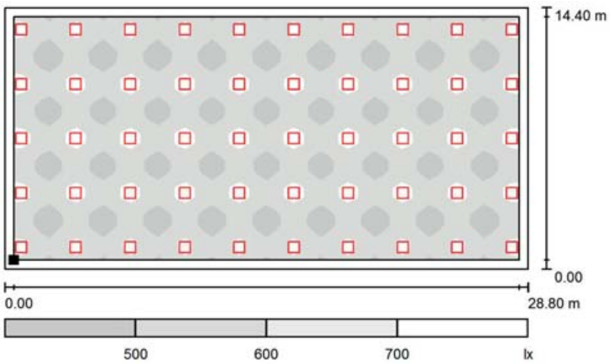



*Fig. 48: Fifty luminaires (L98B50) are all it takes to illuminate an office space measuring 29 x 14 metres using U25 diffusors In the event that you illuminate the space with luminaires with L80B50, you will need more than 60 luminaires.*

**WHAT IS THE CORRECT INTERPRETATION OF THE LxBy FORMULA?**

Example: the service life of U25 luminaires is provided as L98B50 after 50,000 burning hours:

- Where L is the percentage of original luminous flux still achieved after a given period (= LLMF). The U25 luminaires quoted in figure 48 still achieve 98% of their original luminous flux (L98) after 50,000 burning hours (L98).

- Where B is the B-lifetime at the luminaire level. The resulting figure reflects the likelihood that the provided L value is not achieved. Typically the value B50 is used: an average of 50% of the luminaires achieve the provided L-value at the postulated time.

- As standard, ETAP provides the value after 25,000 and 50,000 burning hours, two periods that are representative of your installation's service life.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## 3. INTEGRATION OF ENERGY-SAVING SYSTEMS

LEDs are not only an energy-efficient light source, they also work perfectly with light control systems. This combination allows for a high savings potential, but also creates a few further advantages: LEDs can be dimmed more efficiently than fluorescent lamps and their service life is not shortened by frequent switching. Finally you can also compensate for the degradation of your LED installation with daylight-dependent light control.

The best known light control systems are motion detection, which dim or switch on the light when users enter or leave a space, and daylight control, whereby the light is dimmed depending on the amount of daylight entering a space. A combination of both systems can save 55% or more energy in specific situations. Currently one in six luminaires marketed by ETAP, is fitted with individual daylight control.

*U7 with daylight dependent light control (ELS)*

**LEDs are less sensitive to switching**

LEDs have a number of specific features that make them particularly suitable for use with light control systems. For example, frequent switching has little impact on the LEDs' service life*. This in contrast to fluorescent lamps, which when switched on each time lose a small part of the emitter material in the lamp. This can be seen, for example, in the ends darkening in the lamp. In spaces with relatively short presences – just think of sanitary facilities or corridors – we see that the replacement frequency for fluorescent lamps quickly adds up.

* Except for applications where LEDs are subject to extreme temperatures.

LEDs do not have that problem. Since an LED is an electronic component, which is impervious to frequent switching. In addition, LEDs instantly provide full luminous flux when switched on, which increases user comfort when entering the space.

**Daylight-dependent light control as smart control**

Every light installation loses a percentage of its light output over the years (see 4.1). That is why lighting installations for professional environments are always a little overdimensioned in practice, in order to still achieve the prescribed normative lighting level at the end of their service life. By using quality LEDs in a sophisticated design with optimal thermal management, degradation is reduced to a minimum (10 to 15%).

There are, however, also methods to reduce the remaining 10 to 15% overdimensioning, without compromising on light quality. Today high-end drivers are available that allow to programme a variable current over time, a so-called CLO (Constant Light Output) function. They must be programmed, however, on the basis of the expected decrease in luminous intensity. This in itself is a theoretical projection that leads to uncertainty.

We can also work with a light sensor that measures the actual light level on the work surface and pushes the driver more as the light level drops. This then comes close to what daylight-dependent light control also actually does. Daylight-dependent light control therefore has, regardless of whether it is applied at the luminaire or system level, a double advantage: You will not only save energy, but you can also use it to counter your installation's overdimensioning and thus reduce initial investment costs.

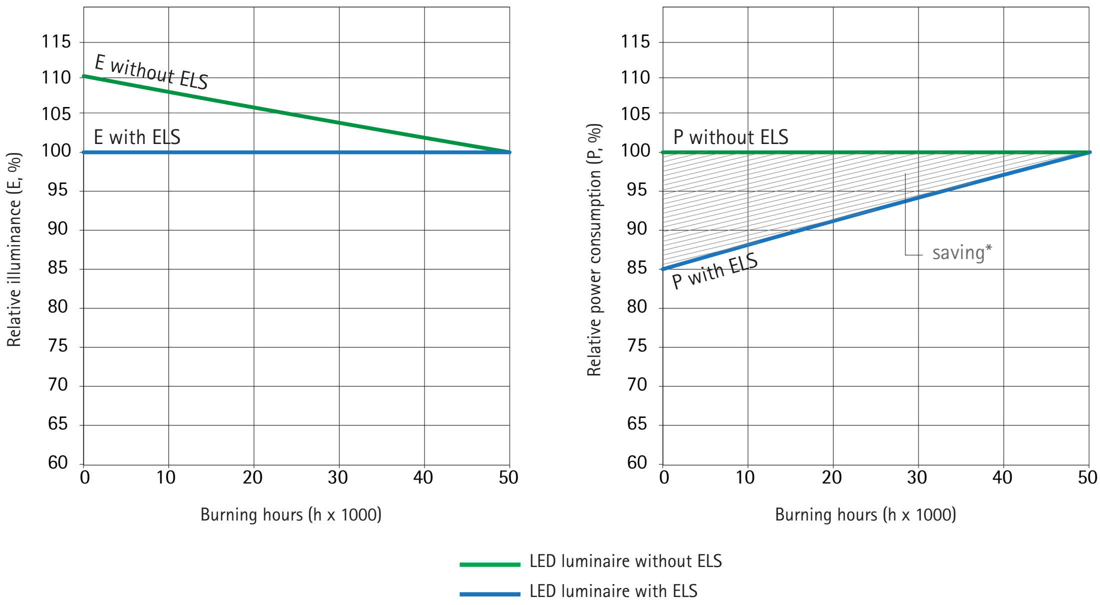


*Fig. 49: A daylight sensor (ELS) ensures that a lighting installation does not have to be overdimensioned. Thus keeping the lighting level constant and saving energy.*

* Extra savings in addition to energy saving achieved due to incident light.

The condition being that there is sufficient margin to increase the current. High-power LEDs typically only run on one third of their maximum power, due to efficiency and luminance control. Therefore there is space for a 10 to 15% surge at the end of their service life. The same also goes for the drivers used today.

And what about the stability and reliability of daylight sensors? As this becomes more important when the daylight-dependent light control is also responsible for the installation's performance. There too, there are very few issues. Daylight sensors do not contain lifetime-sensitive components. They are semiconductor circuits that run on low voltage. In theory they have an MTBF (Mean Time Between Failure) of several hundreds of thousands of hours. This makes them a highly stable and reliable component to control a lighting installation.

# Section 5: Questions and answers

**Q: Where can I go for the international standards involving LEDs?**

A: At www.lightingeurope.org you will find the latest guidelines on LED standards: "LightingEurope Guide for the application of the Commission Regulation (EU) No. 1194/2012 setting ecodesign requirements for directional lamps, light emitting diode lamps and related equipment".

In compliance with the guidelines of the Lighting Industry Liaison Group, these are the international standards with respect to LED lighting:

| Product type | Safety requirements | Performance requirements |
|---|---|---|
| LED lamps with integrated ballast for general lighting with voltage > 50 V | IEC 61347-2-13<br>IEC 61347-1 | IEC 62717 |
| Electronic control system for LED modules | IEC 61347-2-13 | IEC 62384 (Public Available Specification) |
| LED tubes (with double lamp cap) | IEC 62776-1 | IEC 62612 |
| LED Modules for general lighting | IEC 62031 | IEC/PAS 62717<br>(Public Available Specification) |
| LED Luminaires | IEC 60598 | IEC 62722-2-1 |
| The photobiological safety of lamps and light sources | IEC 62471 | |
| LED's and LED modules | IEC 62504 Terms and Definitions for LED's and LED modules in general lighting | |
| CIE Technical Committees | TC2-46 CIE/ISO standards on LED intensity measurements | |
| | TC2-50 Measurement of the optical properties of LED clusters and arrays | |
| | TC2-58 Measurement of LED radiance and luminance | |
| | TC2-63 Optical measurement of High-Power LEDs | |
| | TC2-64 High speed testing methods for LEDs | |

**Q: What is the warranty policy for ETAP LED luminaires?**

A: A warranty period of five years applies to every luminaire. Given the long service life of LEDs, replacements are rather exceptional, but are also guaranteed. ETAP uses universal LEDs (in terms of architecture and footprint). Only changing efficiency and lumen output. When the LEDs fail, ETAP can replace the LED PCBs without problems. The lumen output can be adjusted to the original level if desired. Through the defective PCBs we can also find out to which colour binning the LEDs belong and hence adjust the light colour to the original LEDs. (For details, please consult our warranty conditions on www.etaplighting.com)

# Terminology

**Binning**
Sorting/classifying of (in this case) LEDs in groups with similar properties, e.g., with respect to colour temperature.

**CDM**
Ceramic discharge metalhalide lamp

**CIE**
Commission Internationale de l'éclairage / International Commission on Illumination

**Chromaticity:** colour coordinates

**Cold lumens**
Luminous flux measured at 25°C junction temperature

**Diode**
Semiconductor or conducting electrical current very good in one direction, but not in the other direction.

**Downward light output**
The amount of the total luminous flux directed downward (in a horizontally suspended light source).

**Gamma or cut-off angle:**
Angle in relation to the vertical as in a polar diagram

**Hot lumens**
Luminous flux measured at junction temperature close to practical usage temperature (typically 85°C).

**IEC**
International Electrotechnical Commission

**IES**
Illuminating Engineering Society. Internationally recognised authority in the field of lighting.

**Junction**
Active area in the solid state material in which the light is generated.

**Junction temperature**
Temperature within the semiconductor material (at the PN junction – see below).

**Lead frame**
Basic element for a low-power LED, metal frame that provides external electrical connections, heat dissipation and light reflection.

**LED**
Abbreviation for Light Emitting Diode.

**LED chip**
Light generating semiconductor component

**LED component**
Combination of LED, housing and primary optics.

**LED module**
The LED equivalent of a traditional lamp, but in LED version. According to ETAP's terminology, this corresponds to type 3 - see Section 1).

**LM-80**
American method approved by IES to measure the lumen maintenance of LED components ("Measuring Lumen Maintenance of LED Light Sources").

**LM-84**
American method, approved by the IES to measure the lumen maintenance of LED luminaires (Measuring Luminous Flux and Colour Maintenance of LED Lamps, Light Engines, and Luminaires).

**Luminescence**
Process whereby a light particle (photon) is generated when an atom drops from a higher to a lower energy status.

**Luminous flux density:**
The relation between the luminous flux flowing through a component and its cross-section.

**Maintenance factor**
Factor with which pollution, ageing and lower light output of light sources are taken into account in light calculations.

**PCB**
Printed circuit board.

**Remote phosphorus technology**
Technology whereby the phosphorus needed to generate white light is not put directly on the blue LED but in or on a (glass or plastic) support at some distance from the LED. As a result the phosphorus operates at a lower temperature and in specific cases a gain in efficiency and improvement in service live can be achieved.

**SDCM (Standard Deviation Colour Matching)**
The measure for observable deviations in light colour.

**Substrate**
Support material on which the LED is secured together with the internal reflector.

**TM-21**
Method recommended by IES to calculate the useful lifetime of LED components ("Projecting Long Term Lumen Maintenance of LED Light Sources"), on the basis of LM80 measurement data.


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**TM–28**
Method recommended by IES to calculate the usable lifespan of LED luminaires (Projecting Long-Term Luminous Flux Maintenance of LED Lamps and Luminaires) based on LM-84 measuring data.

**UGR:**
Unified Glare Rating - this is an estimated model expressing the risk of glare. The standard values range from UGR 16 (low glare risk) to UGR 28.

**Useful lifetime**
Economic lifetime relevant to the specific application, which is lower than the average lifetime.

**Wire bonding**
Connection – generally gold – between semiconductors mutually or between semiconductor and lead frame or external electrical contacts.

# Annexe 1: maintenance factor of LED products

## Maintenance Factor % (MF)

| TYPE OF LUMINAIRE | APPLICATION | DISTINCTION | 25,000 h | 50,000 h |
|---|---|---|---|---|
| D1 / D2 / D3 | OFFICE | – | | 63% |
| D42 | OFFICE | – | 88% | 88% |
| E1 | INDUSTRY | – | 83% | 81% |
| E2 | INDUSTRY | – | 83% | 81% |
| E4 | INDUSTRY | E4.0./ | 84% | 83% |
| | | E4.1./ | 83% | 80% |
| E5M - E3M | INDUSTRY | E5M.0./ | 84% | 83% |
| | | E5M.1./ | 81% | 78% |
| E7 | INDUSTRY | E7.1./ (1 ROW LEDS) | 83% | 81% |
| | | E7.2./ (2 ROW LEDS) | 82% | 79% |
| FLARE | OFFICE | – | 87% | 85% |
| RD16 | OFFICE | – | | 63% |
| R7 | OFFICE | without uplight | 88% | 88% |
| | | with uplight | 88% | 86% |
| | | mini | 87% | 84% |
| R8 | OFFICE | – | 84% | 78% |
| U2 | OFFICE | U25 | 88% | 88% |
| | | U21 | 80% | 80% |
| U7 | OFFICE | standard modulations | 88% | 87% |
| | | mini | 87% | 84% |
| UM2 | OFFICE | – | 83% | 77% |
| US | OFFICE | US./LED.25 - /LED.30 | 88% | 87% |
| | | US./LED.35 - /LED.40 | 87% | 83% |
| UW | OFFICE | – | 86% | 84% |
| V2M11 | OFFICE | – | 88% | 88% |
| V2M17 | OFFICE | – | 86% | 84% |
| V2M1F / J | OFFICE | – | 88% | 85% |
| W1 | OFFICE | – | | 71% |


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- All performance figures for ambient temperature Tamb = 25°C
- MF mentioned above is an indicative value: changes with different dust pollution level or cleaning interval.
- MF = LLMF * LSF * LMF * RMF
  (CIE97: publication for interior lighting)
  LLMF: Lamp Lumen Maintenance Factor
  LSF: Lamp Survival Factor
  LMF: Luminaire Maintenance Factor
  RMF: Room Maintenance Factor
- The above calculation of the maintenance factor is based on the following data:
  LSF = 1 ("spot replacement": in case of full LED failure, driver or luminaire are replaced)
  LMF = 0.95 for clean office environments; 0.89 for normal industrial environments
  RMF = 0.94 for clean office environments (reflection factor 70/50/20) or 0.95 for normal industrial environments (reflection factor 50/30/20), subject to three-yearly cleaning. According to CIE 97 2005.
- LLMF based on LM80[1]/TM21[2]

**LLMF (%)**

| TYPE OF LUMINAIRE | DISTINCTION | 25,000 h | 50,000 h |
|---|---|---|---|
| D1 / D2 / D3 | - | | 70%[3] |
| D42 | - | 99% | 98% |
| E1 | - | 98% | 96% |
| E2 | - | 98% | 96% |
| E4 | E4.0./ | 99% | 98% |
| | E4.1./ | 98% | 95% |
| E5M - E3M | E5M.0./ | 99% | 98% |
| | E5M.1./ | 96% | 92% |
| E7 | E7.1./ (1 row LEDs) | 98% | 96% |
| | E7.2./ (2 row LEDs) | 97% | 94% |
| FLARE | - | 97% | 95% |
| RD16 | - | | 70%[4] |
| R7 | without uplight | 99% | 98% |
| | with uplight | 98% | 96% |
| | mini | 97% | 94% |
| R8 | - | 94% | 87% |
| U2 | U25 | 99% | 98% |
| | U21 | 90% | 90% |
| U7 | standard modulations | 99% | 97% |
| | mini | 97% | 94% |
| UM2 | - | 93% | 86% |
| US | US./LED.25 - /LED.30 | 99% | 97% |
| | US./LED.35 - /LED.40 | 97% | 93% |
| UW | - | 96% | 94% |
| V2M11 | - | 99% | 99% |
| V2M17 | - | 96% | 94% |
| V2M1F / J | - | 98% | 95% |
| W1 | - | | 80% |

(1) IES LM-80-08: approved method for lumen maintenance testing of LED light sources
(2) IES TM-21-11: projecting long term lumen maintenance of LED light sources
(3) Source: Osram
(4) Source: Philips

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