Light emitting diodes for lighting 2008

- the light source of the future

Status of Light emitting diodes

Light emitting diodes for lighting

Features of Light emitting diodes

Lighting and energy savings

ELSPAREFONDEN

Light emitting diodes illuminate the interior of the Museum Zeughaus in Mannheim.
Photo: Zumtobel

LIGHT EMITTING diodes for lighting 2008 was prepared in December 2007 by Kenneth Munck, Astrid Espenhain and Katrin Barrie Larsen, Danish Lighting Center for The Danish Electricity Saving Trust.
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The purpose of this report is to provide a picture of Light-emitting diodes for lighting

The area of Light emitting diodes (LEDs) is developing so rapidly, that specifications, characteristics and possible applications are constantly changing. Initially released in 2006 and updated in December 2007, this report takes stock of what LEDs are capable of today, and how they are expected to develop in the future.
The publication is intended for reference use, as well as an introduction to the fundamentals of LEDs and how they function, their advantages and disadvantages, and which savings on electricity can be expected by using LEDs for lighting purposes.
The objective is to inspire architects, engineers, electricians, technicians, lighting designers, utilities, municipalities, the lighting industry and others to utilize this new light source, which without doubt will become a major factor in all forms of lighting in the course of the next 3-10 years.
Chapter 1 explains briefly LEDs historical development and some of the many myths about LEDs. Chapter 2 describes various types of light emitting diodes and how they work, and reviews the most important light engineering parametres. Chapters 3 and 4 deal in depth with their technical properties and provide information for those who wish to design lighting using LEDs. Chapter 5 reviews a number of actual applications and shows how much energy can be saved by using LEDs. Chapter 6 gathers source references and links for further information.

Invented in 1962

The light emitting diode was invented in 1962 by General Electric, but it was not until 1968 that HP and Monsanto could market the first red LEDs. At that time, no one imagined that LEDs would be able to provide white light, or that they could be used for things other than indicators on radios, TV sets and other electrical appliances.
By the end of the 1980's coloured LEDs began to be so powerful, that light could be emitted from them. After that,

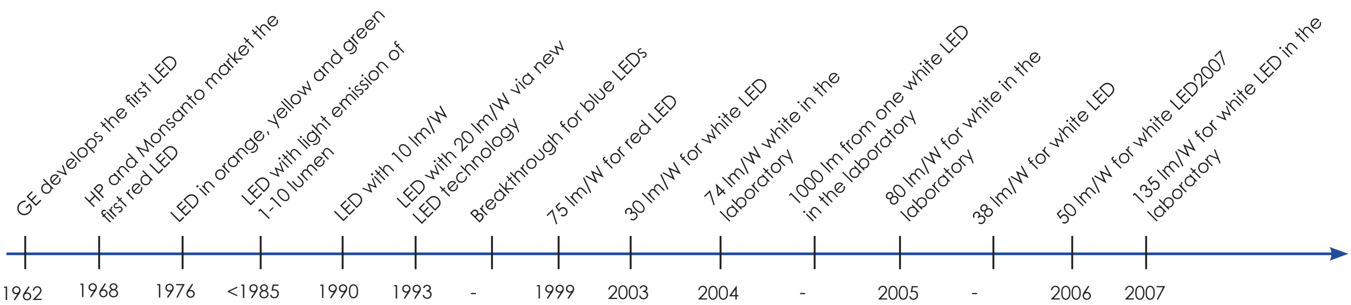
Different types of LEDs with lenses and reflectors.
Photo: Dansk Center for Lys (Danish Lighting Center)

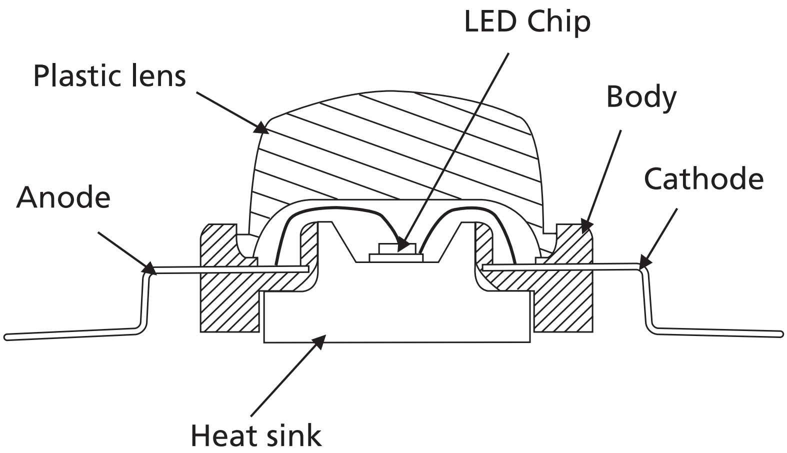
diodes became even more powerful, so that they could be used for coloured effect-lighting. A breakthrough came in 1993 for blue LEDs, which proved to be essential for the development of white LEDs, because blue LEDs can convert blue light to white light via a layer of phosphor. A milestone was reached in 2006 when 50 lm/W was achieved, at that time the magical limit. In 2007, diodes of 100 lm/W were launched.
After a maturing process there are LEDs on the market today, that can be used for actual lighting, both as white light in various colour temperatures, and as coloured lighting. We have achieved an epoch-making small, robust light source of extreme longevity compared to other light sources on the market. LEDs make it easier now to integrate light into architecture, on roads, in furniture and other products in a completely new way. They have become so good and efficient, that they are on the brink of being able to outdo a number of existing traditional light sources. They have indeed shown their potential, and are expected to develop rapidly in the years to come.
Efficiency is increasing considerably, and in recent years has doubled every third year, the latest increase taking only

Light emitting diodes are interesting as light sources because:

- They light in a forward direction
- They have a long lifetime
- They provide full strength immediately
- They can be dimmed without change in colour
- There is no infrared (IR) or ultraviolet (UV) radiation from the light
- They have a significantly higher efficiency than incandescent and halogen lamps. Efficiency is currently at the same level as energy-saving lamps.
- They are mechanically robust
- They are small
- They tolerate very low temperatures
- They can provide very saturated colours
- They do not contain mercury like fluorescent lamps
- They can give savings in electricity

Development of Light emitting diodes from 1962 – 2007





Cross-section of light emitting diode

two years. Whether or not this growth will continue at the present pace only time will tell, but one thing is certain - LEDs have come to stay!

As quality and efficiency improve, LEDs are expected to become widespread in homes, offices and roads, in both the private and public sectors in the course of the next 3-10 years.

LEDs have many advantages which are interesting as far as traditional lighting is concerned, and in addition, due to their size and characteristics, they can be used in totally new areas. In terms of energy, LEDs also offer interesting perspectives as efficiency continues to grow. Efficiency has now reached the same level as energy-saving lamps and fluorescent lamps, and, as such, can compete with the most popular light sources for indoor use.

For outdoor use on roads, paths and in parks, LEDs' longevity, size and robustness bear such economical importance that here, too, it is expected that they will become widely integrated in the near future. As colour rendering is less critical outdoors than in indoor lighting, the demand for outdoor LEDs will without doubt be considerable.

However, it will be some years before LEDs become just as efficient and cheap as yellow high-pressure sodium lamps, cool mercury vapour lamps and impressive metal halogen lamps. Still, there is considerable interest in using LEDs to replace these traditional light sources, because their long lifetimes and robustness provide great advantages in the outdoor lighting sector.

LEDs are therefore the light source of the future, and are even expected in a few years to completely outmatch traditional lamps as far as efficiency and quality are concerned. However, primarily due to the price parameter, there will still be situations where traditional light sources would be the best choice.

What is a LED?

LEDs are small electronic semi-conductor chips, which in themselves radiate light when current flows through them. They are not, as in other light sources, glass or gasses under pressure. They are available in red, green, blue and a number of other colours, as well as white.

Light emitting diodes, along with other light sources, illuminate the area around Højbro Plads in the heart of Copenhagen.
Photo: Philips Lighting

2 Light emitting diodes are widely utilized in a vast variety of situations

Considering how far LEDs and their applications has come today, it is clear that they are already being utilized for many different lighting purposes. Slowly but surely they have encroached into areas that have previously been the domain of traditional fluorescent lighting, incandescent bulbs and halogen bulbs.

The initial uses of LEDs for lighting purposes were in signs for stores, petrol stations and businesses, which required their names or logos lit up at night. LEDs were also used in directional luminaires to show the way, to define road lanes, for traffic signals and on information boards. LEDs' first entry into the area of actual lighting was on illuminated pleasure boats, in kitchen cupboards, on stairways and shelving, and in other places where the demand for light was relatively modest.

Now that LEDs have become more efficient, they can be used for actual lighting purposes such as in desk lamps, corridor, office, stage and façade lighting, and as recessed spots that illuminate walls, plants and other public areas. We have seen LEDs' colour range used for therapeutic purposes, for example in hospitals. Moreover, LEDs are used in combination with traditional light sources, like energy-saving light bulbs with night function, where the LEDs are used at night at a lower intensity. We have also been presented with a number of light sources that have LEDs fitted with standard sockets so that they can replace incandescent and halogen bulbs.

The car and digital camera industries are the ones pushing most strongly for development of cheaper and more powerful LEDs. Today, the majority of modern cars have LEDs as stop lights, rear and reverse lights. LEDs are also fitted as interior lighting in cars and in instrument panels. The aviation industry has begun to appreciate the longevity and vibration strength of LEDs, just as the elevator industry also, to an increasing degree, makes use of the fact that LEDs tolerate vibration and have very long maintenance intervals. Even the exhibition of the Danish Queen's valuable historical dresses at Rosenborg Castle are lit by Light emitting diodes!

From the exhibition "The Queen's Dresses". Light emitting diodes are hidden in the exhibition cases and are powered by batteries. Photo: Lumodan

Market development

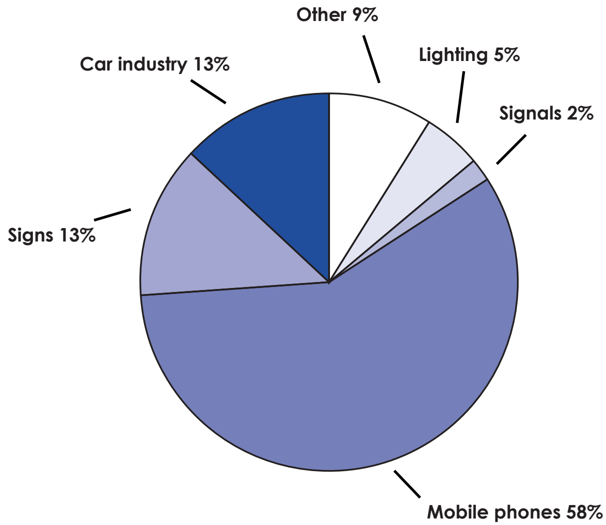
The market for LEDs has grown strongly since 1995, with the mobile phone industry as the most dominant. However, that industry's slowdown in recent years has affected the LED market with lower results.

Apart from the mobile phone industry, the market's growth rate has been 22% per year since 2001. The sale of high-power LEDs in all colours has, according to Strategies Unlimited, grown from USD 2.6 billion in 2003 to USD 4.1 billion in 2007. No other light source can demonstrate such strong growth rates.

Sandia National Laboratories in the USA, which is supported by the US Department of Energy, expects that the utilization of LEDs will gain between 16-47% of the total lighting market over the next 20 years, depending on how strong investments are.

Lm/W stands for luminous flux per Watt. 50 lm/W has been a strategic goal for LED manufacturers and the lighting industry, and this was reached in 2006. Actually, more than 150 lm/W for white LEDs was achieved in the laboratory, proving LED technology's potential, and that very efficient laboratory models already exist.

Calculations show that, when 100 lm/W eventually becomes the norm, the estimated savings in electricity in the US will amount to the output of 29 large power stations. This prospect has made the expansion and development of LEDs a priority on the US energy supply list, compelling the government to venture enormous resources on light diode development. Another quite natural consideration is the great number of jobs and income, that the industry is expected to generate. No other existing technology, whether in the areas of refrigeration, heating or mechanics, can present greater potential efficiency and savings in electricity, and that fact puts an extremely interesting perspective on light-diode technology.

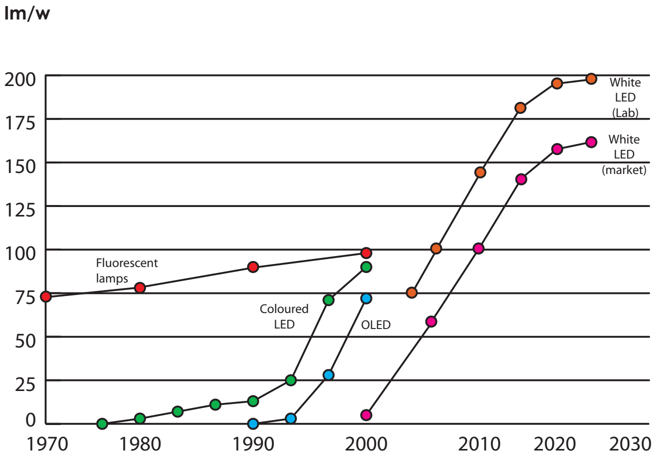


Mobile phones and other hand-held units still dominate the LED market, but new areas are gaining increasing foothold.
Source: Strategies Unlimited (2006)

Effective white LEDs

The most effective white LEDs available have reached an output of 100 lm/W, but they do not illuminate that much. The most effective high-power LEDs diodes provide about 60-70 lm/W, and their colour representation is the same or slightly better than that of fluorescent lights, giving a Colour Rendering Index (CRI value) of 80-85. LEDs with a CRI value of over 90 do exist though. The CRI value is a parameter from 0-100, and represents a light source's rendition of certain reference colours. The maximum of 100 corresponds to daylight, which consists of all the spectrum colours. An incandescent bulb has a CRI value of 99 and most fluorescent lights have a CRI value of 80-85.

Development within light sources



The graph shows the development in efficiency of light sources. With considerable investment in research and development, LEDs can achieve over 200 lm/W. Source: US Energy Department

Commercially available LEDs are fives times as efficient as incandescent lamps, three times as efficient as halogen lamps and equal to energy-saving lamps, which have an efficiency of typically 50-60 lm/W.

In 2005, the largest LED producers, Osram, Philips Lumileds, Nichia and Cree, as well as researchers who work intensely in this sector, predicted that in the course of 2006, we would see white LEDs for sale in retail stores with 50 lm/W and that in the subsequent 3-5 years, white LEDs with up to 80 lm/W would be available. As this goal was reached long ago, progress has proved to be faster than expected. One thing to be aware of however, is that these diodes only provide about 60-70 lm/W.

Researchers at National Sandia Laboratory (USA), among others, have calculated a possible theoretic limit of 200 lm/W, which is much higher than any other available light source, and this is expected to be achieved by 2025.

Efficient luminaires with LEDs

As is the case for light sources, light luminaires can also be more or less efficient. Luminaire' efficiency is defined as the ratio between the amount of light the luminaire radiates in a room and the amount of light the light source itself radiates. Some of the light from a light source is absorbed by the luminaire, for example in a reflector or a shade. Several traditional light sources (for example incandescent lamps and fluorescent tubes) radiate light in several directions, which means that the light has to be led away from the luminaire by a reflector. This reduces the luminaires' efficiency. However, since many diode light sources naturally radiate all light in a forward going direction only, there should be less need for reflectors, and this means higher efficiency and lower electricity consumption.

"Mellow" acrylic pendant with 400 LEDs. Designed by Jesper Sand. Photo: Jesper Sand

Light output

One of LEDs' clear advantages is their small size. However, their total luminance flux (lumen package) is not great. It fluctuates from 0.1 lumen to approx. 240 lumen for the most powerful diodes.

Today, about 240 lumen is sufficient for spotlights, work space lighting and accent lighting. Using diodes for lighting in offices and on roads makes it necessary that a number of LEDs must be used together to produce the same light level as ordinary types of light sources.

Researchers are working to increase the total luminous flux. The most powerful single chip LED on the market provides 240 lumen, still far from a standard 36 W fluorescent lamp with 3350 lumen, and also less than the 60 W incandescent lamp with 720 lumen.

Illuminance levels for offices, stores, roads and paths can be achieved by employing many diodes together.

In 2005 the record was 1000 lumen from a single diode in a research laboratory. Light-diode development is just in its beginnings, so we can expect far better and cheaper light-diodes in the future.

Efficient coloured LEDs

One of the reasons for LEDs' considerable progress has, from the beginning, been the many colour options. Coloured light emitting diodes are used to a large extent for signs, in shops, bars, hotels and for traffic signals.

LEDs are now available in many different colours with each individual diode emitting light in only one specific colour. Diodes in red, green, yellow, amber, orange, blue, cyan and variations of these colours are available.

By mixing light from red, green and blue coloured diodes, it is possible to mix basically all imaginable colours, including white (the RGB method).

Price per lumen

The price of a light source, compared to lifetime and volume of light, is the deciding factor for relevant use. LEDs fluctuate greatly in price from a few Danish crowns (DKK) to several hundred, depending on colour quality, efficiency and volume of light.

The price per 1000 lumen is a frequently used standard in comparing light sources.

A standard 60 W incandescent lamp costing DKK 12 provides 720 lumen, that is DKK 17 per 1000 lumen. White LEDs typically cost DKK 300-1500 per 1000 lumen.

A rule of thumb is that LEDs cost approx. 20-40 times more per 1000 lumen than similar traditional light sources.

Price per unit or per 1000 lumen is not the only economic factor in pricing a complete light installation.

Philips' event-lighting with LEDs, Culture Night in Copenhagen 2007. Photo: Philips Lighting

lifetime and replacement costs are also included. This is where light diodes function significantly better than other traditional light sources, as they often do not need to be replaced before the entire installation needs updating. If potential costs of light source replacement during the light installation's lifetime are included, the result would undoubtedly be positive for LEDs, since they last up to 50-100 times longer than incandescent lamps, 25-50 times longer than halogen lamps and up to 5 times longer than fluorescent lamps.

In addition, the price of LEDs is falling. In the last 2-3 years, the price per LED has dropped approx. 20% per year, and this tendency will undoubtedly continue, while efficiency will continue to increase.

Lower prices can be achieved by purchasing large quantities of LEDs. Uniform colour classifications (bins) cost more because they have to be organized.

11 myths about light emitting diodes (LEDs)

1. LEDs do not give off heat
2. LEDs' lifetime is 100,000 hours
3. LEDs do not provide sufficient light for lighting purposes
4. LEDs do not have sufficient colour rendering for lighting purposes
5. Highly effective LEDs are expensive
6. LEDs are more effective than any other light source
7. LEDs use almost no energy
8. LEDs provide bluish light
9. LEDs can be used for all lighting purposes
10. It is complicated to use LEDs
11. The eyes can be damaged by looking into LEDs

Light sources	Lumen output (lm)	Unit price	Price pr. 1000 lm	Efficacy lm/W	Lifetime	Power	Dimensions etc
Golden Dragon	72	4-4,5€	420	60	50.000	1,2	Ø 20 mm incl. heat sink
Ostar	1000	45€	338	55	50.000	18	Ø20mm
Luxeon K2	100	-	144*)	40	50.000	2,5	10x11,5mm
Fluorescent lamp 36 W	3350	43	13	93	15.000	36	1200x26mm

***) Price for 10.000 pieces.**

The myths are not true:

1. One of the most incorrect assumptions is that LEDs do not give off heat. Actually, heat is one of the most important parametres to have control of in the designing of luminaires for LEDs. Their lifetime is significantly reduced if they cannot release heat. LEDs light does not, on the other hand, contain heat radiation like incandescent lamps and halogen lamps.
2. Longevity is one of LEDs critical strengths. There is no doubt that LEDs can easily function for 100,000 hours, but the question is, how much light is emitted from them at the end of that time. Standard methods (L70 and L50) are now available to specify the lifetime of LEDs, but not all manufacturers comply with these standards when stating lifetime.
3. In a number of cases, LEDs provide sufficient light for actual lighting purposes. Today, the strength of LEDs lies in areas, where the distance between the light source and the object is relatively short, where there is no need for strong lighting or good colour rendering, or where other light sources cannot be used.
4. Colour rendering (Ra value) for diodes fluctuates greatly from 60 to about 91. Quality diodes are available, which are at the same level as fluorescent lamps, and close to incandescent and halogen lamps. In a number of situations, however, colour rendering does not play any significant role, though it must be over 80 for ordinary lighting purposes.
5. In a number of cases, longevity and reduced replacement costs provide better economy than with traditional light sources. Looking at the unit price alone, or at DKK/lumen, LEDs are considerably more expensive than traditional light sources, but the price is dropping constantly.
6. Diodes are closing in on the most efficient light sources. However, fluorescent, metal halogen and mercury lamps are still more energy efficient light sources. Measured in lumen output per added effect (lm/W), the best diodes are more efficient than incandescent and halogen lamps, and are level with energy saving lamps.
7. Of course LEDs use energy, but if is acceptable with less light and the distance to the illuminated object is relatively short, then LED solutions can provide savings in electricity in comparison to traditional light sources. Individually, diodes use from 0.1 - 7 watt, but there has to be several of them to achieve the same lumen output as with fluorescent lamps, metal halogen lamps and other efficient light sources.
8. Today, LEDs are available in many different colour temperatures – both cold and warm. Usually, they are bluish and cold, but are also available in warm white with the same colour temperature as incandescent lamps.
9. LEDs cannot be used for all lighting purposes. Their physical size, the relatively small amount of light, as well as price, can make LEDs unsuitable for certain purposes.
10. A number of manufacturers have developed luminaires that make it just as easy to use LEDs as traditional light sources. In designing luminaires there are a number of new factors which must be taken into account, for example heat, driver, mounting and casing among others.
11. Even though LEDs are very bright and have high luminance, the eyes cannot be damaged by looking into them.

3

It is expected that LEDs for lighting will gain a strong foothold on the world market.

LEDs can be used for many different applications. It has already been proved that they can be utilized for lighting purposes. Even though LEDs are still at an early stage of development, there is no doubt that their popularity will steadily increase. It is expected worldwide that LEDs for use as lighting will gain a strong foothold on the market in the next 5-10 years. In the US alone LEDs are expected to cover over 40% of the total market for lighting in 2025, providing that they can continue to advance at the same speed as in the last 5-6 years.

With promising laboratory results the course for more powerful LEDs has been mapped out. Results of 100, 120 and 135 lm/W for white LEDs have been demonstrated in various developmental laboratories and this contributes to emphasizing their great potential and the many possible applications that exist in LED lighting. For several years, 50 lm/W was the magical limit, but that was achieved some time ago. Today, 100 lm/W is possible and the next hurdle is 150 lm/W. Another goal to be reached is high efficiency with colour temperatures of 2700 K, known from the incandescent lamp, and with colour rendering over 80. When these goals are reached and diodes become cheaper, LEDs will become a natural choice for a great many types of lighting solutions.

Application of white as well as coloured LEDs today is widest for marking, signs and signals. Lighting in corridors, stairways, cinemas, show cases and cold storage are also areas that are expanding at great speed, as is also the case for installations in the car and aircraft industries.

The first stage of LEDs' entry onto the scene was in places where powerful lighting was not a factor, or where coloured LEDs provided new possibilities for coloured lighting.

The second stage was in places where illumination with traditional light sources was not possible, and where installation conditions were difficult or inaccessible. These could be areas that jolt or vibrate such as in cars, elevators, aircraft and portable electronic products, or where LEDs' small size made it possible to integrate light into products.

Zumtobel spotlights with light-diodes at Museum Zeughaus in Mannheim. Photo: Zumtobel

Illumination on bridges and indication of stairways, steps and edges were all initial uses of application, where LEDs were integrated into banisters and railings, or embedded at ground level. LEDs' diminutive size makes it possible to design very small, flat luminaires.

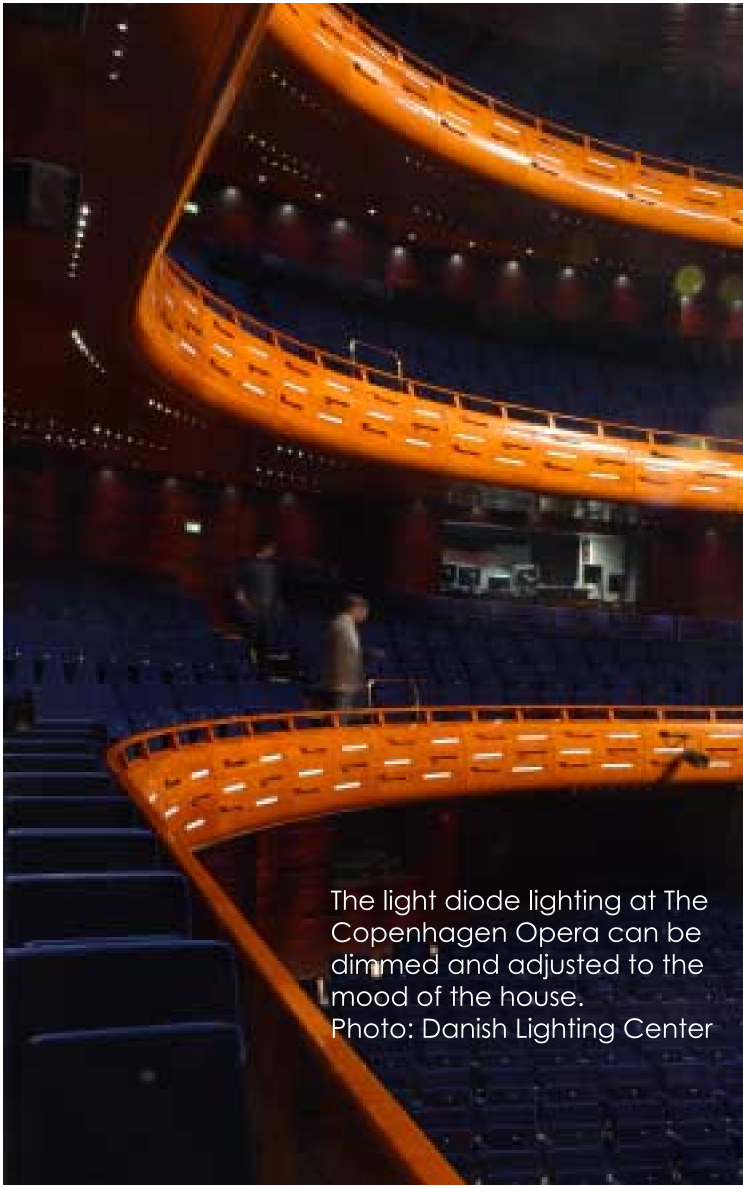
Additionally, there are areas where replacement of light sources is time-consuming because of limited accessibility, or expensive because extra equipment is necessary.

The third stage of development for LEDs is spotlighting and accent-lighting in homes, hotels, shops, buildings, stairways, corridors, museums and so on.

The fourth stage will be the use of LEDs for office and road lighting, areas for which we have only just seen the first examples. In offices, a colour rendering index of over 80 and colour temperatures of around 3000 K are normally required. As some LEDs have difficulty achieving this, they must be chosen carefully. Outdoor lighting will become a very interesting sector as LEDs become more powerful and less expensive. Longevity and long service intervals make them particularly advantageous here. Interesting, too, are the many possibilities for illumination on buildings, town squares and pathways because LEDs can be integrated or embedded while being impervious to vandalism and moisture.

The stages of application

1. Indication and signs
2. Mobile phones and cars
3. Accent lighting with colour
4. Showcases and elevators
5. Corridors and cold storage
6. Shop lighting
7. Office lighting and work lamps
8. Road lighting
9. Ordinary lighting in offices, corridors and schools



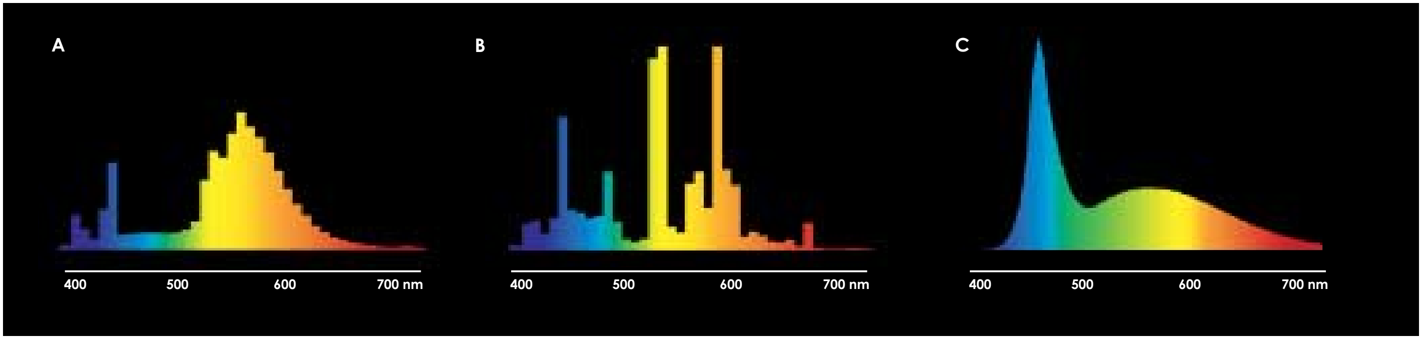
The light diode lighting at The Copenhagen Opera can be dimmed and adjusted to the mood of the house.
Photo: Danish Lighting Center

What can LEDs do?

All light sources have a number of exciting properties and a number of disadvantages. Most important is to assess what the light source can add to a solution. LEDs should not be chosen without first considering the requirements for both light source and lighting, based on a number of technological and qualitative characteristics, as described in the following.
Efficiency measured in lm/W, as described earlier, should always be considered when choosing light sources. Another factor is the light's colour quality. Here, the best LEDs are almost level with halogen and incandescent lamps, and are, in a number of instances, just as good as fluorescent and energy-saving lamps, as far as colour rendering is concerned.
Manufacturers today have great problems in producing LEDs uniformly with regard to colour temperature, light intensity and efficiency. This means that even within the same diode production, there can be substantial production tolerance. This is important to be aware of when working with LEDs, for example when diodes are placed in a row, they need to have exactly the same appearance. Even small differences in nuance in the white light colour can be perceived by the eye and spoil the experience of illumination on a white wall.
Production tolerance means that manufacturers have to sort the LEDs into various colour qualities (bins), and these can be ordered from the best LED manufacturers at extra cost. This sorting means that more uniform LEDs, where the colour difference is within certain tolerances, can be obtained.

Lifetime

Today, there can be quite a difference in LEDs' lifetime and quality from manufacturer to manufacturer. Even though a very long lifetime is specified, it can depend on many things. Awareness of the conditions that must be maintained is important if longevity is to be achieved.
Longevity today varies depending on the various LED manufacturers. The association, ASSIST, which comprises the largest diode manufacturers, has prepared guidelines which recommend that L70, L50, B50 and B10 lifetime values to be specified. L70 and L50 are the terms for lifetimes up to 70% and 50% respectively, of the volume of light that remains. B10 and B50 represent the time, respectively, until 10% and 50%, of the diodes fail. The purpose of all four specifications is to provide the complete picture of a lifetime's correlation to temperature and load current.



A: Spectral distribution diagram for a one powder fluorescent tube of 2700 K

B: Spectral distribution diagram for a three powder fluorescent tube of 4000 K

C: Spectral distribution diagram for a white LED

Source: Electrical light sources, Danish Lighting Center

By looking at these different lifetimes, a far more detailed picture of the products' durability can be obtained. It is important to realise that a number of factors influence longevity and are closely related to the surrounding temperature and how well the LEDs are cooled. The primary parameter is temperature. If the cooling provisions have been poorly designed, then the temperature will reach above the recommended maximum and the lifetime will be shortened. The rule of thumb is, if the chip temperature (the junction temperature) is increased by 10 degrees, the lifetime will be halved. The current has also influence on longevity; the stronger the current sent through the diodes, the higher the temperature becomes in the diode.

LEDs must also be powered by a driver and, if using diodes is to make sense, the driver must have at least the same lifetime as the diodes. Both Osram and Philips Lumileds have 50,000 hours lifetime as standard for their drivers, but as mentioned before, there are many different products with varying quality on the market. It is not unusual to find lifetimes of only 10-15,000 hours for a LED driver, a fact to be aware of if longevity is a requirement.

Colour rendering

A light source's ability to render colour depends on the colour spectrum which the source itself emits. If no light is emitted in part of the spectrum, the source cannot render the corresponding colour. If the light source only emits a small amount of light in a colour area, it will not be able to render all nuances. If it emits a lot of red, warm light like the incandescent lamp, red colours will be emphasized. An incandescent lamp contains all colours, but emits smaller amounts of light in the bluish area, causing considerable colour difference between incandescent lamplight and daylight (even though they both can render all colours).

Ability to render colour is only used for white light sources and is indicated by a colour rendering index – a Ra value between 0 and 100, where 100 is the best. The value states how good the source is at rendering eight reference colours.

Daylight is best with a value of 100, incandescent and halogen lamps have a value of 99 and for energy-saving lamps and ordinary fluorescent lamps it is slightly above 80. Fluorescent lamps, however, are produced with Ra values from 50-98, so versions are available with particularly good colour rendering, almost at the same level as incandescent lamps.

In comparison, the best white LEDs have a Ra value of over 90, which is close to incandescent lamps and the best fluorescent lamps.

However, many LEDs have a value of 70-80, which according to the Danish standard DS 700 is insufficient for indoor work use. Fluorescent lamps can render most colours, but have deep "valleys" in the colour spectrum, making their ability to render colour in these areas poor.

LEDs normally do not have any holes in the colour spectrum but they do have peaks and valleys depending on the type, and the method used to create the white light.

Efficacy

In comparing several light sources' efficiency, two parametres are primarily used; how much light can a light source emit (the lumen package) and the consumed energy (Watt). Efficiency is stated in lumen/watt (lm/W) and this value expresses clearly how well the light source transforms energy to visible light. The most efficient white LEDs on the market have an efficacy of 100 lm/W.

A light source's total light emission, measured in lumen (lm), is also a significant factor. The most powerful diodes can provide up to 1000 lumen (e.g. Osram Ostar) for an 18 W unit with several built-in diodes about two cm in diameter. In the laboratory, Seoul Semiconductor has shown that their standard P4 single chip diode can provide up to 420 lumen with 600 mA. In comparison, a standard 60 W incandescent lamp provides 720 lumen and a 36 W fluorescent lamp about 3350 lumen. Neither lumen nor lm/W tells anything about where in the visible spectrum the light is emitted.

A good example of a very efficient light source is the high-pressure sodium lamp, mostly used for road lighting and with an efficacy of approx. 120 lm/W. It primarily emits light in the yellow area of the spectrum (where the eye is most sensitive) and thus has a low colour rendering index of 20-40.

A number of light sources require a stabilizer which also uses power. The stabilizer´s electricity consumption must be included when calculating total efficiency. Electricity consumption in modern stabilizers and drivers is typically 10-15% of the light source's power consumption.
While there is great focus on light-diodes' efficiency, there are also other factors that can determine how much light falls on a given surface. Distance between light source and object, and eventual loss of efficiency in reflector or shade are considerably significant to the total volume of light that falls on a surface. This volume of light is called the lighting strength and is stated in lux.
Since LEDs are small, they can usually be placed closer to the surface that is to be lit. And since, in contrast to omni-directional incandescent and fluorescent lamps, they only light in one direction, there may be situations where LEDs are more suitable and more efficient than traditional light sources. This applies, in particular, to coloured light, because coloured LEDs are from the outset ideal to provide a specific colour. Coloured light from traditional light sources is always created via colour filters, which reduce efficiency by up to 80%.
Traffic signals is a sector, where coloured LEDs have a number of advantages. Here, LEDs directly provide the red, green or yellow colour, instead of filtering the white light from an incandescent lamp. In so doing, substantial savings in electricity can be achieved. And since LEDs direct light forwards, an efficiency-reducing reflector is not necessary in order to emit backward directed light out of the traffic signal.

Work lamp "Leaf Light" with LEDs.
Design: Herman Miller and Yves Béhar. Photo: Interstudio

Colour temperature

Colour temperature indicates whether light from a white light source is cold or warm, just as a sunset is experienced as warm and a winter's day with clear skies as cold. Colour temperature is stated in Kelvin (K).
An incandescent lamp emits a warm light with a colour temperature of around 2700 K. A halogen lamp is slightly colder with about 3-4000 K. Daylight on a winter's day with blue skies has a colour temperature of over 10,000 K.
The higher the colour temperature, the more cold and blue the light is.
The precise measuring method is based on the light source's frequency spectrum plus a calculation. This corresponds to comparing the white light source's light with a so-called

black object, which is heated. When the light has the same colour or colour temperature as the black object, the object's temperature is measured and this is stated as the colour temperature. The colour temperature is often compared to a red-hot piece of iron: When slowly heated, it is initially red-hot with a low temperature; as it gets hotter it becomes more orange, then more white until finally it becomes white-hot and almost bluish white when the temperature is very high.

LEDs are often rather bluish and cool, and therefore normally have a high colour temperature of 5-6000 K. In order to match incandescent lamps, warm white LEDs have been developed with colour temperatures of 2700-3000 K.

Advantages and disadvantages

LEDs as light sources are a fantastic innovation. They use less space than a thimble, which means that they can be built into places which previously were impossible. They emit light in only one direction with light distribution angles from 5-140°. Traditional light sources emit light in all directions, 360°, and must normally have a reflector (with efficiency loss) or a shade to direct the light where it is required.
LEDs are very long lasting, 25,000-50,000 hours, as stated by most suppliers. The truth is, that the majority of LEDs can last for 100,000 hours, as they rarely break (if they are treated according to instructions). In many cases however, not much light will be emitted after 100,000 hours, because the materials used in diodes age with time. Longevity depends, to a high degree, on how the diodes are treated. Temperatures that are too high, moisture, sunlight and powerful current loads can quickly ruin a LED, which in many ways resembles an ordinary electronic component.
One of the diode's most significant advantages is, that it has no mechanical components. There is neither glass, gas under pressure or a filament that can burn or be loosened by vibration. LEDs can therefore, tolerate strong vibrations.
LEDs also function really well with low surrounding temperatures, because they then are automatically cooled down. Actually, more light is emitted when the LED-temperature drops.
This is quite the opposite of other light sources, such as fluorescent and discharge lamps, which often have difficulty lighting up, and become less efficient at low temperatures.
Diodes require an electronic ballast or a driver. This means that they can be dimmed without difficulty, and regulated without the light colour changing significantly. However, the LED lamps, which are available on the market today, are not intended for dimming unless this is specifically stated on the packaging. Dimming requires that the light source driver contains the necessary electronics.

Mixing of red-green-blue:	**Phosphor converting:**	**Combined phosphor and colour:**
Advantages: Higher efficiency Good colour rendering Many options for colour change **Disadvantages:** Difficult to mix the light 100% Edge effects of coloured light can occur Difficult to control colour stability throughout the Lifetime	**Advantages:** Light from one compact unit Very small in dimension **Disadvantages:** Lower efficiency Complicated production process Limited number of colours	**Advantages** Better colour rendering Lower colour temperature **Disadvantages:** Various types of diodes can change differently over time Can have dissimilar lifetimes and light colours

1. AccentLED with GU5.3 base from Philips

Diodes light up instantaneously, a fact that is utilized in car brake lights. Even though diodes are only approx. 50 milliseconds faster than incandescent lamps in lighting up, the shorter reaction time means that a vehicle's braking length is approx. two metres shorter, which can mean a dramatic difference between life and death.

Another advantage of LEDs is, that they neither emit ultraviolet light nor infrared light (heat radiation). Heat from halogen and incandescent lamps are an energy-craving problem in shops, which often need to have a cooling system.

2. DecoLED with GU10 base from Philips

In addition, textiles and other materials fade when they are exposed to heat radiation and ultraviolet radiation.
Battery power can also be used, since LEDs are fitted with 1.5 - 24 volts and do not draw on great amounts of power. This is particularly so in mobile phones and the like. The emergence of cheap mobile phones with flash cameras is to a high degree due to LEDs.

Colour change and coloured light also belong to LEDs' inherent merits. Colour change can be achieved by using LEDs that have three built-in colour diode chips, in red, green and blue respectively. White light can be obtained by mixing these three colours, and innumerable colours can be mixed by controlling each individual colour separately.
As far as disadvantages are concerned, the majority of LEDs do not yet emit very much light compared to traditional light sources. Typically, diodes emit about 50-100 lumen or 1/7 of the volume of light from an incandescent lamp and only approx. 1/30 of the volume of light from a fluorescent lamp. Diode-manufacturers have, however, begun to pack more diodes together in order to obtain units about 25 mm in diameter, which can emit 1000 lumen.
Today, diodes are supplied in many variations, as semi-finished products, or as complete products. Some are available with sockets, so they can replace existing incandescent or halogen lamps. Others are available as strips or rods, or mounted onto a print circuit board with diverse cooling elements.
Common to all white LEDs is that they use one of two principally different ways to produce white light.
One method is to mix the three basic colours, red, green and blue (the RGB method), to make white light. Since a coloured LED chip can be very small, the three colours can be placed together in a small casing, which mixes the light so it appears as white when emitted from the LED.
The other method uses a UV or blue LED, where the light is converted to white light with a phosphor layer inside

the LED. Both types are available on the market in many different designs.
A method is also seen, where the two technologies are combined. By using both a white phosphor-based diode and a coloured diode, typically red or yellow, improved colour rendering and lower colour temperature can be achieved.
The combi-method is used both at chip level, where different chips are gathered and the light is mixed inside the diode, and at luminaire level where white and coloured diodes are placed next to each other, so that each can be seen individually when looking straight into the luminaire.

Designs

Most diode manufacturers today do not deliver finished light sources that can be installed in an existing luminaire. On the other hand, LED components are manufactured in many different designs for special purposes.
For example, diodes can be mounted on printed circuit boards in long flexible bands with tape on the back, on stiff printed circuit boards, on ring formed ones with screw holes in flexible, moisture-proof units and as building blocks in various packaging. They are naturally also available “raw”, as 5 mm LEDs with two cable legs, or as raw chips with pre-fitted optics ready for soldering onto print circuit boards. All types are normally available in varieties of white and in colours.
Diodes are also available with varying light distribution, which is optimized for diverse applications. Some are side-lighting, others are narrow-beamed and suitable for sign lighting. Others are wide-beamed, or have characteristics that are optimized for application with reflectors or optical lenses.
By now, a number of companies are supplying LEDs that are constructed with built-in sockets and drivers so that they can replace incandescent lamps and halogen lamps in existing lamps and luminaires. These are already available in various DIY centres and lamp shops.
These are found in many different designs. They are most suitable as replacements for reflector halogen lamps because the light distribution and radiation angle for diodes is comparable to that of reflector halogen lamps. This is not always the case when an incandescent lamp is replaced with a corresponding LED.

OLED

A new type of LED is the Organic Light Emitting Diode (OLED). The development of OLEDs is based on a new display technology and can be used to make flat LED light sources. This began in Germany, and today a number of large European companies and universities are working on Organic LED Lighting Applications (OLLA), a joint research and development project. The goal of the project is to be ready with a fully developed OLED lighting product with satisfactory light quality, lifetime and energy consumption in 2008. Specifically, this means a 30 x 30 cm flat light source with white light that has an efficacy of 50 lm/W and a lifetime of minimum 10,000 hours.

3.PAR30 with E27 holder from DanLED

4. AccentLED with GU10 holder from Philips

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Light Emitting Diodes for lighting is a relatively new phenomenon. It is important to be aware of which ones to buy.

In the recent 4-5 years, LEDs have developed significantly where diodes for lightning are concerned. Incredible progress is being made in various technologies and new solutions for fittings appear on the market every day.
It is still a light source under ongoing development. This means that there are not yet the same standards and experience as with traditional light sources. However, certain progress is being made for how the established manufacturers state light data, and for the establishment of standards. As there are many new LED suppliers emerging, it is important to know what to purchase and from whom.
If LEDs are to be used for professional purposes, it is recommended to demand suitable specification and lifetime documentation before investing large amounts in LEDs.
Examples show that LEDs can undergo substantial changes in luminous intensity and colour in the course of a lifetime. However the largest manufacturers, which have been on the market for many years, do guarantee longevity and light output, when the LEDs' operational parametres are followed. Considerably more light is required when LEDs are to be used for lighting rather than as indicators, which just have to be able to glow in themselves. Great demands are now placed on luminaire efficiency, placement and design. The first luminaires with LEDs were just traditional ones with light-diodes installed instead.
Over time, as designers and manufacturers have become more familiar with the possibilities of LEDs, solutions are now seen in which LEDs' special physical and light properties are used to their fullest. Specialists say that LEDs must and should be used in situations, where they add something new to the product, instead of just being used as a replacement for an equivalent light source.
Traditional light sources are usually, for economical reasons, positioned a good distance from each other in order to cover a large area. With LEDs' smaller light emission the lamps must be placed closer together, which normally results in providing a more uniform illumination of the area in question.

Technological properties of LEDs

LEDs' technological characteristics play an ever greater role as they move further and further into the lighting sector. The use of diodes for vehicle lamps, indication lights and torches, does not put great demand on colour quality and colour temperature.
Efficiency, on the other hand, is extremely important. Higher efficiency provides increasing options for applications. For ordinary lighting purposes, colour rendering index and colour temperature are important.
In Denmark there is a tradition for preferring warm light with colour temperatures around 2700 K in both homes and in smaller offices. Cooler colour temperatures are normally used in open-plan offices and in industry. In southern Europe, it is normal to use rather cold light colours compared to what is preferred in Denmark and the rest of Scandinavia.
Due to LEDs' small size, lens systems are very suitable for

LED Module system and LED
Photos: Philips.

spreading or controlling their light. Today, plastic lenses can be produced effectively and relatively cheaply, and many manufacturers have LEDs with lens solutions in their product range. Moreover, a number of lens manufacturers exist that can either develop specific lenses, or carry lenses that fit the most popular LEDs.

Light distribution, that is, how the light is emitted from the light source, is crucial to the way a lamp or luminaire functions. Luminaires are designed for specific light sources and in order to direct the light exactly where it is needed, reflectors and lens systems are being developed.

There are therefore a number of various LED designs available, which provide light distribution that can be adapted to special applications.

Another issue in relation to design of luminaires and lamps with LEDs is the extremely point-formed light source. This provides completely new design opportunities and improved possibilities of directing the light to where it is needed. The more point-formed a light source is, the easier it is to construct an effective and precise reflector or lens.

Because of LEDs' diminutive size, the light intensity or luminance (candela/m^2) is very high. This means that LEDs can easily glare if you look into the light source or on reflecting surfaces. However the eye is also attracted to high luminance and to a play of light on surfaces, so LEDs can naturally provide new attention value. Light plays more easily on shiny surfaces, a fact that jewellery shops have made use of. It is always a case of finding a balance between glare and high luminance.

Thermal design

A new discipline for designers, engineers and luminaire manufacturers, who choose to work with LEDs, is thermal design – that is, heat conditions in luminaires. Even though one of the myths about LEDs says, that they do not become hot, nothing could be more wrong. One of the most important parametres to have control over is the temperature inside the LED. If the temperature becomes too high and exceeds the specified limit stated by the manufacturer, lifetime will be reduced dramatically. As LEDs become more and more powerful, the problem of heat increases. A lot of heat in a small area must be led away through the luminaire via cooling elements, metal sheeting or with the help of ventilation.

There is a direct connection between the temperature inside the LED and its lifetime, and, as with all other electronics, the rule applies that if the temperature is increased by 10 degrees in a specific area, the lifetime will be reduced to half.

The end user does not necessarily need to worry about temperature but, even so, it can be significant for longevity whether it is placed in a closed, warm room or in a cold, well-ventilated room.

One of Europe's largest light emitting diode installations is to be found in the Turning Torso building in Malmö, Sweden. All the corridors in the curved building are fitted with LED panels.
Photo: Louis Poulsen Lighting

To measure and control temperature, some manufacturers state reference points on the circuit boards on which the LEDs are mounted. In order to be able to divert heat, the required size of the cooling surface can be worked out for a given luminaire design, by using normal thermal calculations.
Direction of assembly, as well as choice of affixation and materials, is closely connected to how well a thermal design is constructed.
Metals are good heat conductors while plastics are not. Ventilation and placement of affixation points are important elements to be considered during the construction process.

Safety

Today, LEDs belong in the same category as lasers in terms of safety. In the EU, it is required that CE labelled products comply with the EN 60825-1 standard, “Safety of laser products”. This means that there can be risk of eye damage. Surveys from Agilent and others have shown, however, that eye damage is not a risk with today’s LEDs, but as they become more powerful, it is important to be aware of any future risk. There can be risk of eye damage if LEDs are used in equipment with optics and lenses. It is recommended not to look directly into LEDs at close proximity.

Colour stability – binnings

As can also be the case with fluorescent lamps, LEDs may look different in appearance, when installed right next to each other. LEDs used as spotlights on a white wall, for example, must have the same white colour. Production tolerances today are so great that serious manufacturers sort white LEDs into so-called binnings, or groups that have the same colour. The eye is very sensitive to small variations in white colour, and is also quite sensitive to variations in light intensity or luminous flux which also can vary a great deal from LED to LED. Hence, there are a number of stability issues that must be considered.

LEDs are used here to mark the length of the bridge at Kastrup Bathing Resort, Denmark. Photo: ERCO Lighting

The work lamp, “Diva”, is available either with a fluorescent lamp or with LEDs as its light source. Manufacturer: Waldmann

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Changing to LEDs can give considerable savings in electricity

After a number of years in which LED technology has matured, there is a number of examples of LEDs being used for actual lighting with both white diodes in various colour temperatures, and with coloured diodes. We have only seen the beginnings of energy savings with LEDs.
Savings can be considerable, and in future the use of LEDs as lighting will become more commonplace both outdoors and in, and in both private and public companies.
In the following, a number of examples from Denmark and abroad describe how LEDs are utilized, and report on considerable savings in electricity.

The Horseman statue in Copenhagen

New lighting in the area around Højbro Plads in Copenhagen is a good example of how LEDs can be used to advantage in outdoor city environments. The lighting is created by designer Jesper Kongshaug in cooperation with Philips Lighting. The focal points in the lighting setup are the Horseman statue and an elongated indication of the trees on Højbro Plads. There are 44 LED Uplight luminaires embedded in the ground under the two rows of trees, which stretch from the Horseman statue near the canal to Amagertorv. The trees are lit from below to create a frame around Højbro Plads.
Each luminaire is equipped with six K2 LEDs with a total power consumption of 792 W (880 W incl. driver energy loss). The Horseman statue is illuminated partly by a 60 metre LED string fitted onto the statue's plinth and partly by four Beamer LED spotlights placed on the surrounding buildings. The total power consumption for the 60-metre LED string is 200 W (220 W incl. loss), while the spotlights have a power consumption of 12 W (16 W incl. loss). The LEDs in the string are a mixture of cold white diodes with a colour temperature of 6300 K and a number of diodes in the colour amber. This colour combination makes it possible to vary the colour temperature between 2700 and 6300 K.
The lifetime of the utilised diode lighting is 50,000 hours for both diode and drivers with a reduction of light output of 30%. By using LED lighting instead of traditional light sources, such as metal halogen, the power consumption, is reduced by 40-45%, according to Philips Lighting.
On the square, there are also erected lampposts designed on basis of the original lighting, but equipped with reflectors and light sources, which effectively direct light to where it is required.

The Horseman statue on Højbro Plads illuminated with LED string and LED spotlights. Photo: Philips Lighting

The jogging track in Mølleparken in Aalborg, Denmark, is illuminated with LOA LED bollards, a specially designed luminaire that illuminates the path but not the surroundings. Photos: Gunver Hansen

Photo: Philips Lighting

A jogging track with LEDS

The primary reason that LEDs are suitable for outdoor lighting is that they function optimally with low surrounding temperatures, regardless of how cold they become.

When Eskild Hansen and Gunver Hansen were asked to design a luminaire to illuminate pathways, an obvious choice of light source was LEDs. The result, developed in cooperation with Philips, is called the LOA LED bollard. It is flexible and can be set to illuminate in two, three or four directions.

The bollard is very well suited for lighting paths, both straight stretches and where they fork in several directions. The LOA LED bollard was used for the first time for the illuminating a new jogging track in Mølleparken in Aalborg. It is equipped with five LEDs of the type Philips LMS 3 W and a Xitanium LED driver. The bollard has a total power consumption, including driver, of 17 W. The jogging track is 2.5 km long and is illuminated by a total of 101 bollards.

All the LED modules in the 101 bollards have been individually tuned in order to achieve the correct light distribution on the track. In comparison, similar bollards with compact fluorescent lamps or metal halogen lamps normally use between 22 and 42 KW, including stabilizer.

Vedbæksvænget in Horsens

In November 2007, Denmark's first street lighting with LEDs was inaugurated. In total, 16 65W LED luminaires were installed on Vedbæksvænget in Horsens.

Compared to traditional street lighting with metal halogen lamps, the new lighting installation provides savings of approx. 20% according to LedTraffic. The luminaires, which are developed by LedTraffic in cooperation with Energi Horsens, are equipped with low power diodes with a colour temperature of 3,000 K and a lifetime of 50,000 hours based on a luminous flux reduction of 25-35%. LedTraffic is planning a number of trial setups in several European cities. Before the end of 2007 a further three installations with the new street lights on stretches of road in Norway, Sweden and London should be completed. While the LEDs in the first versions of the luminaires had an efficiency of 70 lm/W and a Ra value of 65, in the new versions efficiency is 90 lm/W and the Ra value 85.

Top: The previous standard street lights.

Bottom: The new street lights with LEDs. During the same process the cables were laid under ground.
Photo: Energi Horsens

Toronto flash

Diodes are an obvious choice where their forward light emission and inherent capacity for coloured light can be utilized. Replacement of traditional light sources in traffic lights with LEDs has been a reality for some years. There are considerable savings to be made here on electricity consumption alone. Most zebra crossings with flashing lights, the so-called "Toronto flash", were previously fitted with 100 W incandescent lamps. In the course of 2006, Dong Energy replaced the incandescent lamps in 100 Toronto flashes in north Zealand and Copenhagen with 13 W diode flashes from Dansk Trafik Teknik A/S. Savings of 128,000 kWh corresponding to 87% is achieved annually. In addition are savings on maintenance. The yellow diode flash's lifetime is 40-50,000 operational hours, which means replacement every 10 years. Incandescent lamps had to be replaced approx. four times a year. Together, electricity and operational savings mean six year's return time of investments at a price of DKK 0.65 /kWh.

The replacement of incandescent lamps with LEDs in the so-called Toronto system has proved to provide improvements and very significant savings in terms of light. Photo: Danish Lighting Center

Aarhus Concert Hall's extension

The lighting in the foyer, corridor and stairs in Aarhus Concert Hall's new extension, which was inaugurated in November 2007, is implemented exclusively with LEDs. The foyer is illuminated with large diode chandeliers designed by Ingvar Cronhammer. There are 17 chandeliers, each 1.2 metres in diameter, and equipped with 217 white power diodes with a total power consumption of 280 W. It was important to achieve a relatively warm tone, so warm white LEDs were used from three different bins in order to achieve a colour temperature of 2900 K, which is close to the light colour of the incandescent lamp. The fitments have a Ra value of approx. 83 and a luminous efficacy of 42 lm/W, which is better than halogen lamps. They can be dimmed (0-10 V) with a regulating area of 5-100% without change in the colour temperature. A row of red diodes is placed around the upper edge of each chandelier to create decorative red reflections on the polished ceilings. In walking areas and stairs, a total of 65 wall lights from Thorn are fitted, likewise with diodes. The wall lights are an existing design, into which 18 power diodes are installed, with a total effect of 23 W per fitment. Like the chandeliers, the colour temperature is 2900 K and the Ra value is 83. Both the chandeliers and wall lights are made by Pablo Diversity ApS. The company states that thermal conditions are good in both luminaires. The chandeliers in particular have a successful thermal design. The diodes junction temperature is approx. 50oC with maximum luminosity. The wall light's thermal design utilizes the fact that the fitment is aluminium, giving a junction temperature of approx. 70°C with maximum luminosity.

Ingvar Cronhammer's diode chandeliers and wall lights from Thorn illuminate the foyer in Aarhus Concert Hall. Photo: Lars Hjorth, Pablo Diversity ApS

Cold storage with LED lighting at Chr. Hansen
Photo: Chr. Hansen / Lumodan

LEDs in cold storage

As previously mentioned, LEDs function optimally at low temperatures, and also light up immediately, so they are the obvious choice of light source for cold storage and other low temperature rooms. The first and largest Danish installation where this form of lighting from Lumodan is being used, is at the company Chr. Hansen, which processes enzymes and cultures for the food industry. Here, diode lighting was installed in a 1,000 square metre freezer room, with temperatures down to -55°C. Previously, incandescent lamps were installed with a total effect of 20 kW. This was the only lighting that could function at very low temperatures. The diode lighting's total power requirement is 5.5 kW, which provides electricity savings of 72%. Moreover, large amounts of energy are saved in cooling, since diodes do not release the same amount of heat as incandescent lamps. The utilized diodes have a colour temperature of 6500 K and provide illuminances of 130-150 lux, which before was 50-70 lux.

In November 2007, Novo Nordisk had diode lighting installed in a new 300 square metre freezer room in Bagsværd. Here, 17 ceiling luminaires were supplied by LedTech, each with 1150 LEDs and a power consumption of 60 W per luminaire. The colour temperature is 4500 K, which is achieved by mixing diodes with 6000 and 3000 Kelvin in the ratio 75% to 25%. The lifetime of the diodes is 50,000 and their Ra value is 85. Novo Nordisk has also gained considerable electricity savings. In cold storage rooms with fluorescent lamps, the lights are often left on because re-ignition at low temperatures takes too long. With LEDs, the light goes on immediately and can be switched on and off as needed. If this factor is included, and it is assumed that the diode lighting is switched on only two hours a day, a return time of under one year is feasible according to LedTech. Novo Nordisk is installing LEDs in a further 1200 square metre building comprising a cold storage room and corridors.

LEDs in food coolers

In the American supermarket chain, Wal-Mart, intense work has been done on identifying areas that could provide the greatest energy savings. One area is the lighting in food coolers. Previously, the lighting consisted of integrated fluorescent lamps that were switched on 24 hours a day.

LEDs can tolerate being switched on and off often and provide full intensity immediately they are switched on. They were the obvious choice for a trial run with new lighting in the chain's refrigerated food coolers. In cooperation with Watt Stopper, Wal-Mart's engineers developed diode lighting with movement sensors, which were initially tested in two of the chain's shops.

In both shops, the installations were connected to a data logger, which registered data over a period of six weeks. In order to gain as large electricity savings as possible, the movement sensor was set at a 30 second delay. It appeared that the LEDs in the coolers were switched off respectively 44% and 47% of the day.

If the light in the coolers is switched off 40% of the shop's opening hours, and reduced cooling needs are also taken into account, Wal-Mart can make a calculated total saving of 92%. The supermarket chain is now installing diode lighting in all 450 shops and has calculated a return time of approx. two years.

Wal-Mart in the US has equipped its food coolers with diode lighting as part of a large energy saving campaign.
Photo: GE Lighting

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CIE
www.cie.co.at

Lighting Research Center
www.lrc.rpi.edu

Philips Lumileds
www.lumileds.com

Osram
www.osram-os.com
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http://lighting.sandia.gov/

ZVEI
www.zvei.org

Danish Lighting Center
www.centerforlys.dk

The Danish Electricity Saving Trust
www.elsparefonden.dk


At Flintholm Station in Copenhagen, the beams of the roof construction are illuminated by LEDs.
Photo: Osram

Mood-creating diode lighting in the bar at the football club, PSV in Eindhoven. Photo: Danish Lighting Center

This publication is a status report and is intended for reference use and as a fundamental introduction to the light emitting diode, or LED, and how it functions. LEDs have a number of completely new properties and in the long term, a very large potential for savings in electricity.

The report takes stock of the technical lighting properties involved, as well as possibilities for application today. It also outlines some of the many future expectations for LEDs for lighting.

The objective is to inspire architects, engineers, electricians, technicians, designers, power stations, municipalities, the lighting industry and others to make use of this new light source in an energy efficient way.