# Sustainable lighting design: LED and beyond

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"LED and energy-efficient lighting", p. 56

More than a decade has passed since LEDs were first offered as an architectural light source. In the beginning we were enchanted by how small fittings could be made, their effective light colours, and promises that they would last forever.
Since this beginning we have learned a lot. Probably the most important lesson is that we need to look very carefully at what we are told by those who market lighting!
At the same time, the focus on energy efficiency in lighting and buildings in general has also become a major design factor. Sadly, the early emphasis on LED life hasn't been borne out. Rather, it was refocused on the "low energy" aspect of this technology, with regular announcements from major LED manufacturers of higher and higher efficiencies of the chips. Unfortunately, this wasn't reflected in the actual lighting products available on the market
Nonetheless, we are now seeing products that can provide effective white light in useful quantities with reasonable colour quality. Products are still very expensive in comparison to more conventional technologies, but typically have significantly longer life spans if installed and operated properly. Unfortunately, we also see a huge volume of low quality, low price LED products both in retail lighting and, to a certain extent, in the commercial sector.
LEDs are still a totally different kind of light source to other technologies. They are inherently directional, thus excellent when you want to direct light to a specific area, but less useful as a general non-directional light. They also operate at much lower temperatures, and need to, in order to have a good operating life and deliver a good operating efficiency. These factors make LEDs generally unsuitable for replacing other light sources in designs and even forms of existing light fittings.
Despite this, we continue to see LED options being provided for existing fitting designs more frequently than fittings specifically designed around the LED light source. We also see a large number of LED lamp replacement products for fluorescent tubes, GLS lamps, and Low Voltage reflector lamps. None of these make best or even merely good use of LEDs and generally produce significantly less light, as well as totally inappropriate photometric output for the fittings they are being used in.
Most new luminaires available on the market today, however, have been designed specifically for LEDs. Many companies now offer specific LED downlights that show acceptable outputs when compared to compact fluorescent downlights. In some cases, but definitely not all, they show potential energy savings over the more conventional technologies.
This comes at a cost. Typically, a good LED downlight will cost 2 to 3 times the price of a quality compact fluorescent downlight. If you compare them to a cheap commercial downlight, the cost multiplier is in the region of 8 or 10. In return for this, you can get a degree of energy savings in the region of 30 %, a much longer life expectancy, and therefore lower maintenance costs. The LED will be typically rated at 30,000 hours to 50,000 hours. However, the system life is likely to be substantially shorter depending on the quality of fitting design, manufacture, and the quality of control electronics. Thus, LEDs don't offer the universal, energy efficient, incredibly long life solution for lighting. I don't believe that they ever will – they are just another tool in the lighting designer's armoury of light sources. Generally speaking, LEDs are most appropriate where their unique characteristics are most useful, such as:

- situations where long life is important, for example where maintenance is very disruptive. This includes transport applications such as tunnels, railway stations, airports, aeroplanes, trains, escalators etc.;
- situations where the physical characteristics of LEDs are uniquely suited, such as marker lighting for orientation or colour lighting, where LEDs are by far the most efficient light source;
- applications where specifically low lighting levels are needed, such as emergency lighting and night lighting in hospitals;
- locations where heat build-up can cause problems, typically high-end retail display cases and supermarket display refrigerator cabinets.

Some applications that would seem appropriate for LEDs remain stubbornly out of reach. Museum lighting is one such application. Lower typical lighting levels and a desire for lower operating temperatures are key considerations. However, colour


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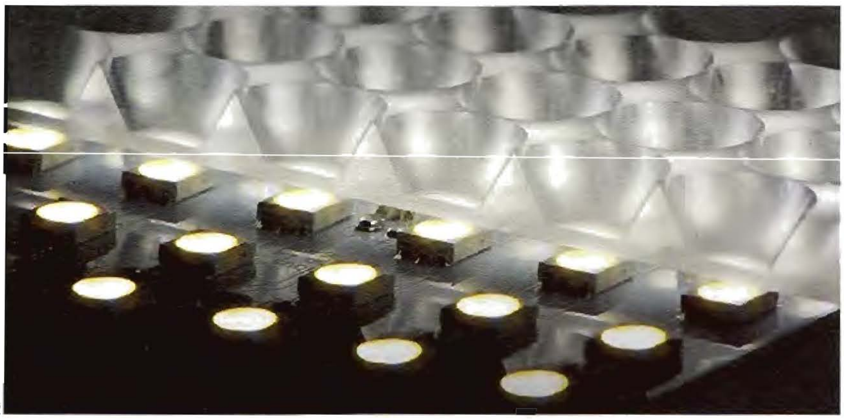

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1 Al Tijaria tower in Kuwait (Lighting design: KSLD). LED colour change fittings are integrated into the facade at each office floor. In the crown of the tower, cold cathode colour change is used as there is no air conditioning in this part of the building. Thus, it is too hot for LEDs to run reliably. The lighting colour changes according to the wind speed. The LED sections use about half of the power of the cold cathode sections
2 LED module with acrylic glass diffusor.
3 Key data of the most common light sources

quality is also vitally important. It is now possible to deliver acceptable colour (better than 90 $R_a$), but this comes at a very significant cost in efficacy. Typically, the best LED systems deliver less than 10% greater energy efficiency than the most efficient low voltage tungsten halogen fittings, at a 2 to 3 times higher cost. LEDs are generally expected to eventually replace Low Voltage Tungsten Halogen, but it isn't likely that they will ever deliver the same range of light output within the same physical size, simply due to the required heat dissipation necessary to keep the LED healthy. Be very wary of products claiming to be energy efficient replacements for existing low voltage lamps!

*Lighting efficiency beyond LED*

If LEDs are not the universal solution what should we be considering as sustainable lighting? This is a difficult issue that needs looking at at a very fundamental level. We have been bombarded with marketing telling us that this or that technology is "energy efficient" and using this to replace what you have today will save the planet. Unfortunately the European legislature has been persuaded that this is a valid solution and increasingly, legislation, planning requirements and client's briefs demand a technology solutions. This can be tempting as it is easy to make a difference that may be visible in reduced energy bills and can be easily demonstrated in numbers on paper. In fact the numbers around lighting energy use are incredibly variable, more so the further up the chain you go. At present we do not know how much power is used for lighting compared to other energy uses. This information will become available as intelligent energy metering becomes the norm.

The particular efficacy of a light source or light fitting doesn't tell us how much energy it will use in an installation. Neither does the total installed lighting load tell us this. What is important is the amount of energy used by a lighting installation in an operating situation. There is a measure for this that is detailed in EN 15193. This is the Lighting Energy Numeric Indicator (LENI). It is expressed in kWh per square meter per year (kWh/m²a). This is the real measure that determines the energy use for lighting.

Reducing our LENI is is a two part problem. First is an exercise in design that requires quite fundamental analysis and challenges some of the dogmas of lighting enshrined in standards and codes of practice. Second is a matter of psychology and control to optimise the use of lighting equipment in operation.

Sustainable lighting design is basically providing the appropriate lighting quality and quantity that is required for the users of the space you are designing for. Rather than blindly following standards and recommendations, this requires a full enquiry and analysis of the space. For many years office developers have demanded full task level working light across the entire floor area of an office space, this would typically be 500 lux. This is based on many standards required for detailed work that have gradually increased, not because we actually need more light now than we did 30 years ago but because it is now possible. As the majority of floor space in an office comprises seating areas and corridor space and we are almost universally using computer displays for tasks that are self illuminating, designing to an overall level of, say, 200 lux with provision for local task lighting easily reduces the lighting energy demand by 50%. Add into this lighting controls that dim lights down when there is sufficient daylight or when no one is actually in an area (using absence detection) and your saving is proportionately increased by 20% to 40%.

Similar, very significant, savings can be made in other ways. It is amazing, for example, just how much apparent brightness can be given by careful consideration of surface finishes. In many applications a quick repaint can reduce the requirement for electric light. In designing new buildings consideration of reflected light needs to be brought to the fore. The difference in reflectivity between a bright white and a muted off white can be as

| Light source | Lighting efficiency (lm/W) | Life expectancy (h) | Colour quality ($R_a$) | Starting time |
|---|---|---|---|---|
| Incandescent bulb | 7–17 | 1000–2000 | 99-100 | immediately |
| Mains Voltage Halogen lamp[1] | 9–22.5 | 25–4000 | 99-100 | immediately |
| Low Voltage Halogen lamp[1] | 11–27.5 | 25–4000 | 99-100 | immediately |
| White LED | 2–70[2] | 200–50 000 | 60-95 | immediately |
| Compact Fluorescent Ballast Integrated Lamp | 35–70 | 6000–15 000 | 82-85 | 1-2 secs |
| Fluorescent lamp | 50–114 | 8000–20 000 | 80–97 | 1-2 secs |
| Cold cathode fluorescent lamp | 40–80 | 30 000–50 000 | 75-95 | 0.5-1 sec |
| Metal halide lamp | 65–105 | 9000–15 000 | 70-90 | 3 min.[3] |
| Mercury vapour lamp | 30–60 | 10 000 | 45–58 | 5 min.[3] |
| High pressure sodium lamp | 70–150 | 20 000–32 000 | 25–40 | 8 min.[3] |
| Low pressure sodium lamp | 100–180 | 12 000–18 000 | 0-25 | 15 min.[3] |
| Induction lamp | 50-72.5 | 20 000–60 000 | 60-94 | 1-5 secs |

[1] Values vary according to wattage. Low wattage lamps are least efficient. IR coated lamps are most efficient.
[2] Value for standard commercially available LEDs. Includes correction for practical operating temperatures. LED outputs are typically quoted for junction temperature of 25°C. However practical operating junction temperatures usually 70°C to 120°C.
[3] Values apply to conventional types of ballast. Re-start time after switch off can be 15 minutes.

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4 Street lighting with LEDs
5 Museum of Islamic Art, Doha (Architect: I.M.Pei Interior designers. Wilmotte Associés SA): Lighting for exhibition rooms with 12 V halogen spotlights
6 Savings potential by means of various measures in the existing building
7 Fashion shop in Paris (Interior design: SAO/Arne Quinze). Decorative lighting with 2.5 V LED spots, some as a rail system, some as 4-lamp modules
8 Industrial hall in Geroldswil/Schweiz: Basic lighting with fluorescent lamps as a light strip system, control in relation to level of daylight
9 Engineering office In Heimstetten (Client and planning Ingenieurburo Hausladen): Optimised daylight utilization, additional workplace lighting with fluorescent lamps in pendant luminaires, control in relation to level of daylight
10 LENI limits in accordance with DIN EN 15193 (for non-CTE lighting)

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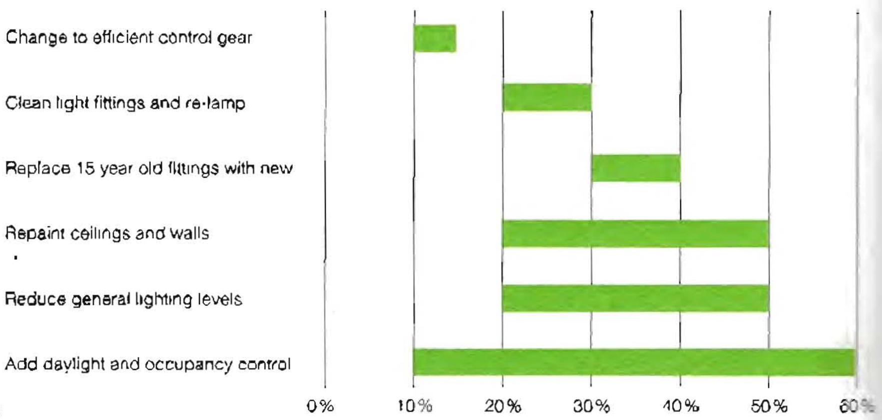
much as 20 % particularly if the finish colour is warm and the light source is a cool white or vice versa. I am not suggesting that everything should be uniform bright white, just that the impact of finish colours needs to be considered much earlier in the design process. I have lost count of the number of times I have asked architects and designers how they would be decorating a space while in the course of designing the light only to be told that they would not be even thinking about this until much later!
While in the vein of bashing architects I should also talk about daylight. The arrangement of fenestration seems to be considered only as an aspect of how a building looks from the outside on many projects, rather than derived from the specific location and its availability of daylight. Low ceiling levels also restrict the possibility of daylight reaching across the floor particularly on deep floor plan buildings. There are many good reasons for these poor design choices from the lighting point of view. Many are to do with economics of building and the fact that the heating or cooling of most buildings consumes so very much more energy than the lighting.
I have touched on the intelligent application of lighting controls. Switching lighting off saves 100 % of lighting energy! We very naturally switch on lighting when we need it or even just when it is available. Our eyes have evolved to work best in the very high levels of normal daylight so any deep shaded areas, such as indoors, feel relatively dark particularly if there are no reasonably large windows that let us see the outside world. For the same reason we rapidly and easily adapt to gradually increased lighting levels and are not so naturally inclined to switch lights off. Lighting controls are particularly necessary in shared areas where no one person has ownership of the space. However a degree of subtlety is necessary to prevent the users of the space feeling that they are being deprived of light. Another aspect of our evolution that affects our vision is that our peripheral vision is optimised to detect change and movement so we automatically turn our heads towards a sudden change. This happens when you switch lights on and off suddenly. It is therefore sensible to dim lights up and down gradually so that people are not aware that levels are changing automatically.

*Sustainable lighting beyond energy*
So far, we have discussed energy use as the predominant environmental impact of lighting. As long as the majority of Europe has electricity generated by fossil fuels, this will remain the case. However, it isn't the only impact, and much of what we are encouraged to do to save energy use through technological change creates other environmental issues. As we (hopefully!) move towards more renewable electricity generation, the focus on other impacts will need to be sharper. The greatest single issue is the use of mercury in lamps. This extremely poisonous metal is present in almost all efficient lamp technologies except LEDs as the fundamental method of creating light from electricity. Typically modern fluorescent lamps contain between 3 mg and 18 mg of mercury. In Europe, its use has been banned from pretty much every other industrial application. As long as it remains inside lamps it isn't a problem. The issues arise when lamps need to be disposed of. While we like to think that such lamps are recycled, the majority in most EU countries still end up in landfills, where the mercury eventually leaches into the ground water. The EC Director General of the environment estimated that in 2002 4.5 to 9 tons of mercury per year in defunct lamps were dumped. With 1 gram of mercury enough to contaminate all the fish in an 8-hectare lake, this is a sizeable issue. Even if the lamps are recycled and some of the mercury is recovered, it leaves us with a problem: What to do with the mercury? As an increasing quantity of lamps are made in the Far East, while the EU has banned the export of mercury, there is currently a one-way traffic from newly re-opened mines in China (causing massive pollution there through lamp manufacturing) to mercury sequestration facilities in German salt mines! Of course, not only the mercury ends up in the mines. As it isn't cost effective to extract mercury from the contaminated waste, lots of glass and phosphors end up buried with it, rather than being reused.
As I mentioned, LEDs don't contain mercury and, therefore, don't pose this prob-

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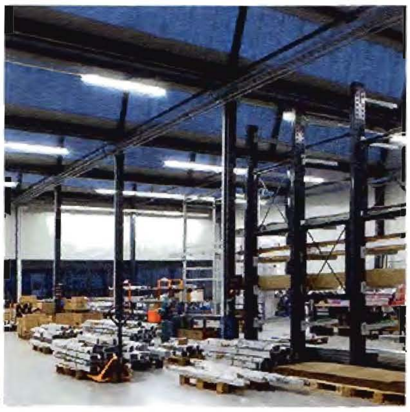
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lem. They do raise other issues when it comes to replacement and disposal. Largely, they show little problem in resource use if they remain in use for their entire life. However, many LED products will be disposed of well before their end of life. For example, a high-end retail installation will run around 3270 hours a year, 9 hours a day and 7 days a week. A quality LED product will have a life of e.g. 40,000 hours or 12 years and 3 months. It is very unlikely that a quality retail outlet will not have been refurbished twice in that period. As things are at the moment, lighting is usually thrown out, hopefully to recycling, during a retail refurbishment. There needs to be a very significant change in attitude to re-use of lighting if the LED system is to achieve its intended life and its minimal environmental impact. The whole consideration of re-use of lighting equipment needs to be developed to generally reduce the impact of lighting, as does the requirement calling for a greater proportion of recycled base materials in new equipment that we specify. Aluminium can have a very high proportion of post consumer aluminium waste included in material for new manufacture. Some lighting manufacturers require 80 % recycled content in the aluminium castings they use in light fittings. Glass can also be recycled. However, post consumer glass tends to be less clear than new material, so it is best used in decorative rather than optical lighting applications. Plastics are the least recyclable of materials commonly found in lighting. Typically, lighting plastics have a high content of flame inhibitor chemicals, and such plastics aren't suitable for re-use. It is, however, possible to specify plastics recycled from other applications particularly for internal parts, where mixed or discoloured plastic components are acceptable.

*Outlook*

So where are we heading towards? One of my fascinations in lighting is that it is constantly changing. New technologies keep appearing, older ones improve, tastes and fashion changes and new imperatives need to be considered. However, that doesn't prevent me from making predictions. I predict that not much will visibly change in the next 5 years. Lighting installations typically last a long time. You might see office building refurbishment on a 15-year cycle, large retail maybe 10 years, and only the fashion-conscious retailer or restaurateur will typically change things in around 5 years or less. When it comes to roadside lighting, a life figure of 30 years is typically quoted. However, installations can last much longer. Industrial lighting will also last 20 to 30 years, as will lighting in many museums and art galleries.

In 5 years we will be lucky if a third or even a quarter of lighting installations will be significantly changed. This also returns us to the question as to whether technology change can significantly alter the energy use of lighting. Basically, adding a control system to an existing installation that is properly designed and thought through is much more likely to deliver significant energy savings. I predict that LEDs will form a very significant proportion of new installations

Apart from very few instances, we are unlikely to see all LED schemes materialise, and we may well see other technologies playing a significant role in lighting. OLEDs are promising as area light sources, but are struggling to meet efficiency standards and acceptable operating life. Plasma light sources will become common in industrial, street, and theatre lighting, and possibly even for exterior lighting, depending how quickly the technology scales down to something small enough to use. I also predict that we will have some pretty serious consideration given to reducing acceptable hours of use for commercial and street lighting. Hopefully, there will be an end to office buildings with lights left on all night - a bigger waste of energy I cannot conceive. I hope that this process will be done intelligently as to not reduce our cities to dark and gloomy places by the outlawing of building identity lighting. I also hope that lighting energy use legislation will move away from technology banning and power density to LENI or a similar standard that addresses the issue of lights left burning when not required. Lastly, I hope that the general lighting standards are reconsidered to move away from prescriptive horizontal illumination and look to measures and design processes that deliver the right light at the right time in the right place.

| Type of use | Lighting standard | Installed lighting power (W/m²) | LENI manual (KWh/m²a) [1] | LENI automatic (KWh/m²a) [2] |
|---|---|---|---|---|
| Office | * | 15 | 42,1 | 35,3 |
| | ** | 20 | 54,8 | 45,5 |
| | *** | 25 | 67,1 | 55,8 |
| Educational | * | 15 | 34,9 | 27,0 |
| | ** | 20 | 44,9 | 34,4 |
| | *** | 25 | 54,9 | 41,8 |
| Hospital | * | 15 | 70,6 | 55,9 |
| | ** | 25 | 115,6 | 91,1 |
| | *** | 35 | 160,6 | 126,3 |
| Hotel | * | 10 | 38,1 | 38,1 |
| | ** | 20 | 72,1 | 72,1 |
| | *** | 30 | 108,1 | 108,1 |
| Sports facilities | * | 10 | 43,7 | 41,7 |
| | ** | 20 | 83,7 | 79,7 |
| | *** | 30 | 123,7 | 117,7 |

[1] with manual lighting control [2] with automatic lighting control

10 * basic ** good *** comprehensive fulfilment of lighting design criteria acc. EN 15193, table F.2