

Design and Technology for Efficient Lighting

R. Faranda, S. Guzzetti and S. Leva
*Department of Energy – Politecnico di Milano,
Via la Masa 34, 20156 Milano,
Italy*

1. Introduction

The conscientious use of energy resources has become an indispensable prerogative in our society. In the last years the artificial light, that represents a significant amount of the total consumption of electrical electricity, is becoming a significant aspect order to obtain economic and energy savings. Besides, it's important to consider that, over the last decade, global demand for artificial light grew at an average rate of 2.4% per year and the growth in demand is expected to continue for the foreseeable future (IEA, 2006).

For these reasons, in recent years, several governments have been increasingly deploying a range of policy measures to improve lighting energy savings. These measures include address to the lighting system as a whole (i.e. building codes, as EN 15193, that limit the maximum power demand of the lighting circuit for unit area and mandating the use of controls and zoning in new build and retrofits) and for specific lighting components (i.e. minimum energy efficiency requirements for lamps and ballasts, IEC 62442 or DIN IEC 60294).

Given this, nowadays the lighting systems are developed to use the more efficiency lights and to optimize energy consumption. Specifically, researchers are working, both in private and in public field, on the proper design approach, on the efficiency of light sources, on the performance of lighting equipment and on the development of intelligent control systems¹; the results obtained give good prospects of success.

1.1 New concept of lighting design and lighting system

In this section a new approach to lighting design will be discussed. As a matter of fact, in the last years the lighting concept is moving from a functional point of view, in which the lighting systems are use only to light, to a new point of view, in which the lighting system is an instrument to guarantee comfort and environmental well-being at the end users.

This modern concept of the lighting has had an important benchmark in "CIE Symposium on Lighting Quality" of 1998. In fact, the results of this symposium are used by Engineer, Illuminating Society of North America (IESNA) to develop a new approach to lighting design. This model, proposed in IX Edition of manual lighting (IESNA, 2000) is, schematized in Fig. 1. It states that the quality of lighting design strictly depends on the interaction of

¹ Reduce energy consumption is much more complex in most less-developed countries because there are not often reference standards on recommended lighting and because efficient technologies have a selling price higher than the old and inefficient solutions.

three fields: the individual, the light integration with architecture and the ergonomic and environmental implications (Blaso, Pellegrino 2007).

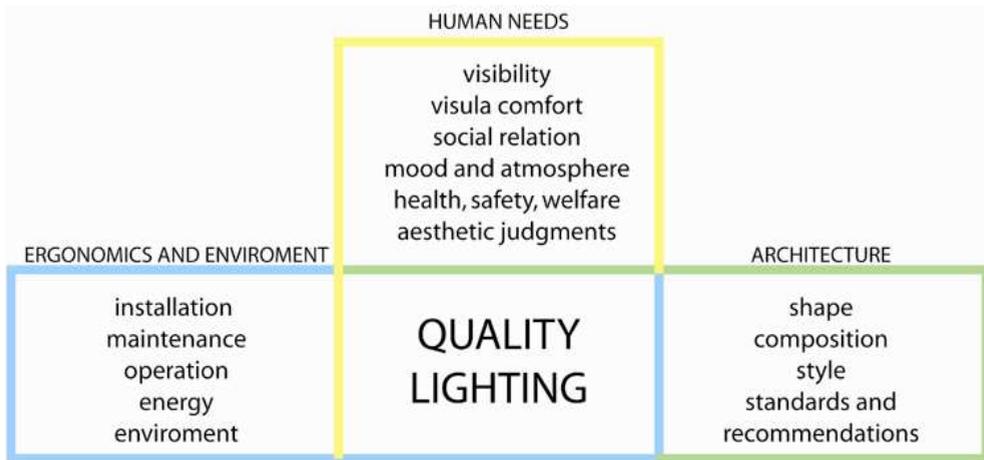


Fig. 1. Schema about quality of lighting design (www.infobuildossier.it)

Another official confirmation of this new approach to lighting design is the introduction, in the lighting sector, of a new indicator the *Ergonomic Lighting Indicator* (ELI), about the quality of light.

According to this indicator, the quality of light is classified on a scale based to five criteria:

- Performance (with reference to appropriate standards):
 - illuminance (right amount of horizontal illuminance according to required);
 - glare control;
 - low luminance;
- Appearance:
 - space (e.g. bright, open and friendly space);
 - colour (e.g. natural colour temperature and rendering);
- Comfort:
 - shadows (e.g. soft shadows, neither too harsh nor too diffuse);
 - modelling (e.g. cylindrical illuminance, friendly illumination of faces);
- Emotion:
 - light distribution (e.g. architectural lighting of surfaces and objects in the room);
 - preference (e.g. personal preference for lighting situation);
- Individuality:
 - own light (e.g. personal lighting, personal use of switches);
 - individual control (e.g. lighting chosen for individual benefit).

These new guidelines for the quality of lighting can be also important tools to improve the energy savings. In fact the light quality, characterized by dynamic light and its ability to create different scenarios, can be achieved only using modern devices, such as efficient sources, luminaries with high performance, systems for integration of natural light and for intelligent control, which, as now known (Benediktsson, 2009.), are also very energy-efficient solutions.

In the following, with reference to the difference fields of lighting and to the energy saving, the most important characteristics of lighting system will be described. Furthermore particular emphasis will be dedicated to the technology and to some case studies.

2. The fields of lighting

As mentioned in the introduction, lighting represents a substantial proportion of global electricity consumption, equal to 17,5% (IEA, 2006). But it is important to know that there are different types of lighting, each with particular characteristics, to properly treat the issue of energy savings.

In particular, regarding energy consumption, the largest amount of energy is used in offices and commercial buildings (43%), followed by: residential buildings (31%), industrial buildings (18%) and outdoor lighting (8%) (IEA, 2006).

There are many types of lighting designated for different applications and there are significant savings opportunities in each of them. In fact, as estimated by IEA, at least 38% of global lighting energy consumption could be saved cost-effectively for the end-user by greater use of existing efficient lighting technologies. In the following paragraphs the main field of lighting will be described.

2.1 Public lighting

The public lighting is an essential element for our safety. In fact, the term “public lighting”, as stated by standard “lighting road” (EN 13201-1), defines all fixed lighting installations which provide user a correct visual perception of the outdoor public traffic areas during periods of darkness, and are designed to ensure the safety of drivers, the proper disposal of traffic and the safety of all people. To ensure safety, it is very important that artificial light has a good quality (e.g. high CRI, Color Rendering Index). In fact, streets and towns pleasantly lighted promote socialization in outdoor public spaces even in the hours of darkness. The presence of people discourages illegal activity and therefore the public safety increases.

But despite their great importance, the most of existing lighting systems are very obsolete and, therefore, they're inefficient. Besides this, speaking about energy consumption, it is also important to consider that the number of street lighting will greatly increase in the coming years (over all in the African countries or in the Chinese countryside, etc.).

Therefore, to save energy will be important both to increase the efficiency of existing lighting and to pay attention in the design of new systems.

Fortunately there are a number of areas in lighting systems where energy saving initiatives can be still implemented in street luminaries. These can broadly be categorized into the following areas:

- the lamp;
- the luminary;
- the ballast;
- ‘intelligent’ systems;
- remote monitoring devices.

The lamp

The efficiency of lamps has improved significantly in recent years and the type used can have significant impact on the amount of energy required to run them (the specific characteristics of the lamps will be described in the paragraph 3.1).

Although this, today the most common type of lamp used in street lighting is still high-pressure mercury lamp², an extremely inefficient and pollutant source. It is followed by low-pressure sodium (LPS) lamp; it's a very efficient type of source but with a bad quality of light (it glows yellow-orange).

Policies of energy saving gives positive signal so that lamp changing initiatives (re-lamping) have taken place in a number of countries due to political awareness. This initiative is an important first step because, such as recent studies have indicated, "*shifting to high-pressure sodium (HPS) or metal halide lamp (from older models) could result in an efficiency improvement in the lamp itself as high as 40%*" (E-Street, Project Report).

Concluding, changing sources can be just considered as a simple and cheap way to save energy.

The luminaire

Street luminaires of the most existing road lighting are inefficient. In fact, today a typical luminaire installed absorbs more than 50% of the light emitted by the light-source; this is due to the low-performance of the optical system. Besides this, the lamp installed is often of the old generation, therefore the global lighting system is very inefficient. The importance of both the lamp and luminaire efficiency in street lighting is indicated in Table 1, which reports data from an European study (Eurelectric, 2004) that are generally applicable all around the world.

	Luminous efficacy of lamp (lm/W)	Average luminaire efficiency (%)	Total efficiency (lm/W)
Low-pressure sodium	68-177	25	17-44
Tubular high-pressure sodium	70-150	45	32-68
Elliptical high-pressure sodium	59-124	30	18-37
High-pressure mercury	34-58	30	10-17
Metal halide	61-85	35-40	21-34
Ceramic metal halide	70-76	45	32-34

Tab. 1. Total efficiency of combinations of lamp and luminaire for outdoor street lighting

Today there is a very large range of luminaires available commercially and these can have significantly different optical properties, which have a large impact on the efficiency of the lighting system. The most efficient optical systems can absorb less than 10%.

In conclusion, "*development in lamp size and the characteristics in optical design mean that the efficiency of modern luminaries can be 25-30% higher than those based on old lamps*" (E-Street, Project Report).

² Among OECD countries, Japan has the highest share of mercury vapour lamp sales at 42% of all HID High Intensity Discharge lamps, in Europe they account for 30%, in Australia 18% and the United States only 8%. In non-OECD countries, mercury vapour lamps account for about 93% of HID sales in Russia and a more modest 61% in China (OECD/IAC, 2010).

The ballast

Such as said, the most used lamps in street lighting are the discharge lamps (HID). They cannot be connected directly to the supply line, they need a device to obtain the necessary circuit conditions for starting and operating, called ballast.

There are two types of this device: electro-mechanical (traditional power supply system) and electronic (new generation power supply system).

Recent studies have shown the use of electronic ballast allows to save about 7% of energy and to extend lamp life by 30% respect to traditional ballast (E-Street, Project Report). Considering also that electronic ballast can control the luminous flux performing and the regulation of the flux emission, the energy savings may be estimated of about 30% compared to traditional solution (electro-mechanical ballast).

Finally, also recent European and National standards suggest the use of programmable clocks as switching on and off devices and luminous flux reduction, of 30% from 24.00 to 8.00, to save energy (UNI 11248, 2007 and L.R. n°17, 2000).

The ballasts will be analyzed more detail in the paragraph 3.2.1, while '*Intelligent*' (*lighting control*) *systems* and *building automation devices* will be discussed in the paragraph 3.2.2 and 3.2.3 respectively.

Today, besides to these consolidated systems to save energy, new solutions are beginning to experimentes LED (Light Emitting Diode) solutions. An example is the project implemented by the City of Los Angeles, called Clinton Climatic Initiative (www.clintonfoundation.org). The project will involve the replacement of 140,000 traditional street luminaries with LED luminaries and it will be executed from 2009 to 2013. The City will install remote monitoring devices on each of its new LED street luminaries, allowing the Los Angeles Bureau of Street Lighting to collect real-time data on its system performance at the fixture level.

Thanks to this project, the designers claim that the City will dramatically reduce its energy consumption due to efficient of the new luminaries and control system and will reduce its street lighting maintenance costs due to the long life of LED lamps and the remote monitoring device (expected payback of the investment should be 7 years). In particular energy savings (post retrofit) should be of 68.640.000kWh/year and CO₂ savings should be 40.500t CO₂/year.

In conclusion, today a modern "*effective energy-efficient street lighting should use a balance of proper energy-efficient technologies and design layout to meet performance, aesthetic and energy criteria required by pedestrian, motorist, community residents municipalities and utilities*" (NYSERDA 2002).

2.2 Lighting for work-spaces

Most countries official issue recommend illumination levels that installers of lighting systems are requested to attain in the work-spaces.

These informations are collected in specific standards. They define the performance levels of lighting workstations and their direct environment. They also include tables with lighting requirements in accordance with the type of work and the visual task (e.g. in European countries the standards are EN 12464-1 "Light and lighting - The Lighting of work places" Part 1: Indoor work places", EN 12464-2 "Light and lighting - Lighting of work places - Part 2: Outdoor work places").

But despite this, today most lighting in work-space do not respect guidelines on recommended lighting levels and lighting systems are usually installed via rules of thumb applied by electrical fitters. This way of working means that the light levels guaranteed are often higher than necessary. This causes great waste of energy and discomfort to workers.

After this general introduction about work-place lighting, in the following only the office will be analyzed. This choice was made because there are many different types of work-places (according to the different economies in different countries) each with specific characteristics and problems, in opposite office is a common reality to all countries.

In the last years, standards that define the maximum power consumption were written to reduce the energy waste in the buildings, so in the offices. For example, in Europe the reference standard is EN 15193 Energy performance of buildings - Energy requirements for lighting - Part 1: Lighting energy estimation, march, 2007.

Specifically, these standards define the energy parameters that lighting systems must follow and how to get them. For example, the European Standard EN 15193 defines the parameter LENI (*Lighting Energy Numeric Indicator*) that describes the yearly energy consumption for lighting per square meter for the buildings. This indicator changes according to the energy needs required by the visual tasks. For offices LENI is equal to 36kWh/m² (EN 15193, 2007).

When possible, the guidelines contained in the standard should be followed by lighting designers. This would lead to an huge energy savings.

Besides this, in this sector, simply the replace of same devices now installed, such as:

- magnetic ballast with electronic ballasts;
- traditional linear fluorescent lamps (LFL) with slimmer fluorescent tubes with efficient phosphors (common known as "super LFL");
- obsolete luminaries with high quality luminaires characterized by efficient optical systems;

produces savings that are just impressive.

Finally, the global lighting system could be made more efficient, 35-40% typically (IEA, 2006), through the use of sophisticated devices, such as:

- time-scheduled switching;
- occupancy sensors;
- daylight-responsive dimming technologies.

Also, these devices provide ensure great comfort to the worker because they create lighting quality (e.g. light dynamic, customizable lighting performance etc.) and, as already shown by many researches, it positively influences the health and well-being of users (Boyce et al., 2003) and the performance of office work (Newsham, Veitch, 1996).

Concluding, for the lighting office sector there are now great opportunities for saving energy, increasing final-user comfort. This can be achieved thanks to the technologies described. In fact all these devices are already fully mature and ready to be used.

2.3 Lighting for artistic and architectural buildings

2.3.1 Artistic buildings lighting

Lighting of the art sites has historically always made through incandescent lamps, especially halogen. Because, until not long ago, these luminous sources were the most used in projectors/spotlights to create accent lighting, due to their high color rendering index (CRI 100) and their very compact dimensions.

These sources are also highly inefficient (15-20lm/W) and they have a short life time (2000-4000h). The lighting systems of these areas consume a lot of energy and the costs of maintenance are very high (it is necessary to replace lamps frequently). Given the cultural importance of these places and that until recently lamp with performance like halogen doesn't exist, the theme of energy saving has always been a secondary thematic in the

museum system. However recently, although the distrust of museum curators, thanks to new technology performance, either in terms of the qualitative aspects of light and energy, there are first projects according energy-saving.

In summary, the main tools which are available today in order to have good results in energy saving are:

- sources;
- natural light;
- management systems.

Sources

Technological improvements have allowed to get very efficient sources (lm/W) with a high color rendering index (CRI) in a lot range of correlate color temperature (CCT). Specifically we are speaking about fluorescent, ceramic metal halide and LED.

Some examples:

- linear fluorescent lamp (Philips, T8, Master TL-D Graphics 90, 58W): 60lm/W, 98 CRI, CCT 5300/6500K (Price list Philips, 2009);
- metal halide lamps with ceramic burner (Philips, CDM-TC Elite Mastercolour, 70W): 100lm/W, 90 CRI, CCT 3000K (Price list Philips, 2009);
- power LED (CREE, XLamp XR-E LED): 56,8-87,4lm/W, CRI 90, CCT 2600-3700K (datasheet, CREE, www.cree.com).

Natural light

The light of the sun is the best light which our visual system can perceive colors, shades, materials etc.. Therefore give emphasis to the natural light, inside the museum spaces allows the visitors to enjoy the beauty of the exposed works. Besides this, the contribution of natural light, if well managed by the installation of artificial lighting, through detection systems and management, can obviously become a valuable item that reduces energy consumption.

In conclusion, at the planning of lighting systems is important to carefully evaluate the natural light and prepare its integration to maximize the use of energy resources, and even more design new buildings according the guidelines of daylighting.

Management Systems

Especially in a places like a museums, where the visitors are not the same number all over the day, but it depends on certain time slots, an intelligent lighting system is essential in order to save energy. The main devices which allow an appropriate use of energy resources are presence sensors, daylight sensors, flow regulators and fragmented light. In fact, thanks to these appliances the lighting systems work only when it is necessary, according to the presence of someone and with natural light (see 3.2.2).

An example of modern lighting museum, designed with energy-saving criteria, is the museum of contemporary art "Punta della Dogana" in Italy in Venice (Spotti, 2009).

The lighting system, designed by Studio Ferrara Palladino, has planned to use for the entire lighting system only discharge lamps with high energy efficiency, high color rendering to a colour temperature of 4200K. These choices have allowed to reduce the consume for a museum, which is calculated at full capacity around 25 W/m² walkable levels of illumination that can reach average values of 300 lux. The other factors that have led more savings have been the contribution of natural light provided by skylights, and the use of control systems connected to the DALI controllers throughout the building (the system used DALI allows the adjustment from 0 to 100% for each unit individually). With these elements in fact it was ascertained through a period of monitoring (the entire period of the inaugural

exhibition), an energy consumption of the system during the hours of opening to the public less than 10W/m².

2.3.2 Architectural lighting

Architectural lighting aims to show buildings' architectural beauty and to make it can enjoyed by people at night. Architectural lighting often makes buildings more beautiful at night than daytime. Ugly buildings, such as old shopping mall or ruins of industrial archaeology, become fascinating architectural volumes through good lighting. As a matter of fact, when the light changes, our perception and our experience also changes. This is the main concept of architectural lighting (Egan, 2002).

On the other side, in this period, in which the energy saving is one of the main goal, light something for only aesthetic reasons can be considered a huge waste, especially if it is done with inefficient lamps or luminaries. Until a few years ago, this was what happened. In fact, architectural lighting, particularly outdoors, was realized by floodlights with halogen lamps.

In the last years the way to realize architectural lighting has very changed. The main change is that buildings are no longer illuminated from the bottom, but they are illuminated from top to bottom to avoid problems of light pollution and to save energy. Another change is that more efficient lamps and luminaries are used: linear fluorescent luminaries (for wall wash lighting) or floodlights with discharge lamps, in particularly metal halide lamps (for accent light).

The use of these sources has led to decreased energy consumption for this particular kind of lighting. In fact, the light efficiency of traditional halogen is equal to 15-20lm/W on the contrary fluorescent lamps are characterized by light efficiency of 60-100lm/W and metal halide of 80lm/W, more or less. Also maintenance costs are decreased because the life time of the new efficient lighting sources is much longer than halogen lamps (5/6 times).

Finally, in this field the last major innovation is LED device. Thanks to LED, small luminaries, that can easily be hidden in volumes of buildings (inside throats, under the eaves, etc.), have been made. In this way the architecture is not contaminated by any device: only light. Moreover LEDs have introduced another possibility: create bright and dynamic skins on the exterior walls of buildings. In fact, only the LEDs, small and easy to dim, can transform a wall into a big screen.

For this particular type of architectural lighting -"surfaces of light"- the LED is the solution energetically and economically successful. In fact, as shown by recent studies (Gregorius, Siti Handjarinto, 2007), although LED's initial cost is very high, its operational cost, in a long term, is cheapest of all other solutions; also if it is compared to luminaries characterized by discharge lamps.

Concluding, in architectural lighting's field where energy saving is not the main goal, today there is great potential for energy savings. This is very important because architectural lighting is now a factor that characterizes, more and more, our cities. Such as we saw in these few lines, aesthetic choices, technology and energy saving can travel together.

2.4 Residential lighting

Globally, residential lighting consumes about 31% of total world lighting electricity and it constitutes about 18.3% of residential electricity consumption. High consumption is caused by used of inefficient lamps, in particular incandescent in many countries, and of luminaries with low luminaire output ratio (LOR); this means that only a small amount of source-

lumens makes a useful contribution to overall illumination. In fact, total system (luminaire and lamps) efficacy is average equal to 16.8 lm/W (IEA, 2006).

Another factor that does not help save energy is the absence of standards and the possibility of direct control in this lighting sector.

For all these reasons, residential lighting is thus the least efficient of all grid-based electric-lighting end-user sectors and is also the one with the highest theoretical potential for improvement.

In fact, without a palpable change in lighting quality, simply a market shift from inefficient incandescent lamps to CFLs (Compact Fluorescent Lamps) would cut world lighting electricity demand by 18% (IEA, 2006). About this, fortunately, almost all governments are in the process of phasing-out traditional incandescent lamps (General Lighting Service, GLS). This process began since early 2007 and it will end in 2020. (OECD/IEA, 2010).

In the last years, the conception of residential lighting is changing. In fact, today, the house isn't only a place in which we sleep and eat, but it is seen as a place in which other different activities take place: relaxing, socializing, working etc. For this reason, lighting designers work increasingly to realize installations in private dwellings. In these cases, the welfare of the end-user, pleasant environment and the quality of light, often coincide with the energy savings. This happens because these kinds of lightings are realized with efficient luminaries of new generation (usually characterized by LED or fluorescent lamps) and they are often controlled by home automation systems. Indeed, if the dimmers and devices for on/off lights and for adjusting their intensity are properly managed, lighting scenes best suited to each need and significant reduce consumption can be obtained (Pizzagalli, 2009).

In conclusion, today in the lighting residential sector there are large energy waste, in most situations. Fortunately, the new government policies, the new conception of home, seen by more and more people as comfortable and wellness place, and the new technologies open up interesting prospects.

3. Technologies for energy saving

Currently there are already many technologies (eg. efficient lamps, control systems etc.) and as many in development (eg. power LED, O-LED, etc.), which could provide interesting energy savings, if correctly used them. In the following paragraphs the main of these will be described.

3.1 Light sources: state of the art and development

3.1.1 Traditional light sources

Lamps have a very important role in determining energy consumption of a lighting system. There are many lamps, each one with very different characteristics both for energy efficiency and for spectral emission. For this reason the right luminous source for each particular application have to be choosen.

In particularly, there are three main families of lamps: incandescent, discharge an combined incandescent-discharge (now a days this kind is very rare).

Complete overview of all different types of lamps is shown in fig. 2.

Regarding to the different fields of application before analyzed, the mainly characteristics of luminous sources with the best quality light and efficiency are:

- *for public lighting*: HSP (70-120lm/W and average CRI) or Ceramic Metal Halide, CMH (67-104lm/W and very high CRI);

- *for the offices:* LFLs (60-100lm/W and very high CRI);
- *architecture and museums:* LFLs (60-100lm/W and very high CRI), CMH (67-104lm/W and very high CRI) and LED powers (60-90lm/W and high CRI);
- *for the residential sector:* CFLs (35-80lm/W and high CRI).

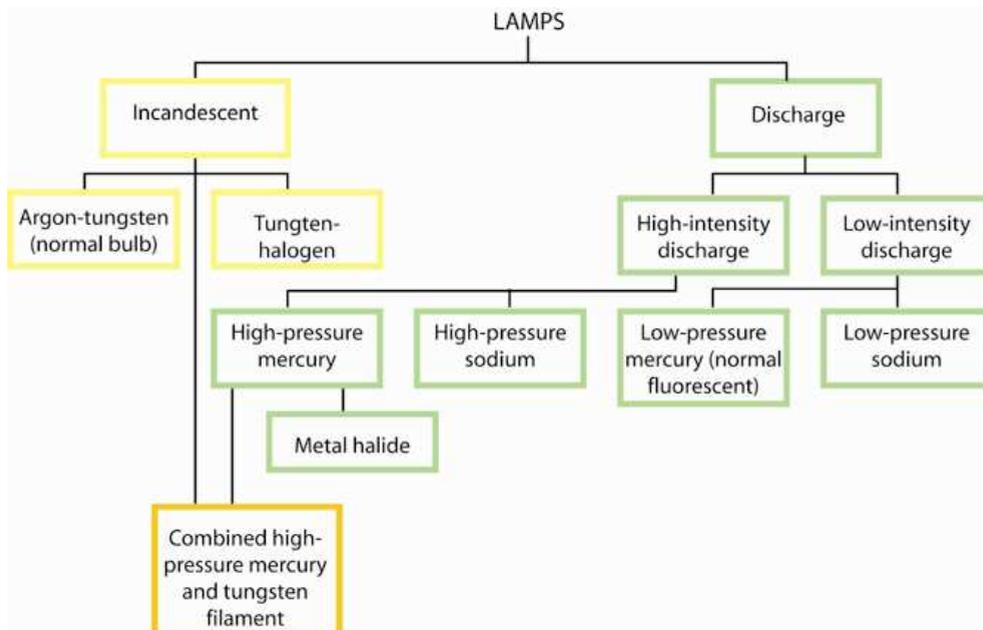


Fig. 2. General schema lamps

Not to dwell much too, all other light sources and their specifications have been collected in the table 2.

Lamp category	Characteristics	Applications
Incandescent lamps	Very low efficacy and low life. Low investment costs, high running costs. Dimmable. Reflector lamps for concentrated light beams. 10-15 lm/W with lamp life of 1000 h. Very high CRI and low CCT.	For general, local, ambient and spot lighting. Not suitable where high lighting levels are necessary.
Halogen lamps (low voltage)	Very small lamps, capable of producing highly directable light beams. Some losses in the transformer. Low to mid efficacy with low to mid lifespans. 15-33 lm/W with lamp life of 2 000 to 6 000 h. Very high CRI and low CCT, but slightly higher than incandescent.	Highly suitable for spotlighting.

Halogen lamps (high voltage)	Slightly higher efficacies than incandescent lamps. 15–25 lm/W with lamp life of 2 000 to 6 000 h. Very high CRI and low CCT, but slightly higher than incandescent.	Suitable for spotlighting or illuminating large areas (floodlighting).
Linear Fluorescent Lamps	Mid to high efficacy depending on type, with highest efficacy when used with electronic ballasts. 60–100 lm/W with lamp life of 7 000 to 20 000 h. High to very high CRI, with broad range of CCT available.	Wide application. Highly suitable for general indoor illumination, especially to provide economic, even illumination and for all low- and mid-bay lighting. Not suitable for spot lighting.
Compact Fluorescent Lamps, ballast integrated	Directly interchangeable with incandescent lamps: greater energy efficiency, much longer life expectancy. Not dimmable. Also available as reflector lamps. 35–80 lm/W with lamp life of 5 000 to 15 000 h. High CRI and broad range of CCT available.	For almost all areas where incandescent lamps are used: general, local and spot lighting.
Induction lamps	Very long life of 30 000 to 100 000 h and mid to high efficacy of 55–80 lm/W. High CRI and wide range of CCT available.	Relatively high first costs mean they are most economic when used in inaccessible areas with high maintenance costs, such as tunnel lighting.
Metal halide lamps	Mid- to high-efficacy lamps covering a broad lumen-package range. Warm-up time of a few minutes. Dimming difficult and sometimes suffers from poor lumen maintenance. 47–105 lm/W with lamp life of 6 000 to 20 000 h. High CRI and broad range of CCT available.	Suitable for mid and high-bay indoor lighting and outdoor lighting, whenever long operating hours apply. Poor lumen maintenance. Most commonly used for industrial and street lighting.
Ceramic metal halide lamps	High-efficacy lamps covering a low to high lumen-package range. Warm-up time of a few minutes. Dimming difficult. 67–104 lm/W with lamp life of 6 000 to 15 000 h. High CRI and low- to mid-range CCT available.	Suitable for indoor display lighting (as a substitute for halogen lamps) and for mid and high-bay indoor lighting. Also provide street and architectural lighting.
High-pressure sodium lamps	High- to very high efficacy lamps covering a broad lumen-package range. Poor to moderate CRI and relatively long warm-up periods 70–120 lm/W with lamp life of 5 000 to 30 000 h. Low to mid CRIs and low CCTs (orange-yellow hued light).	Economic street lighting and industrial lighting where high CRI is not required.

Super high pressure sodium lamps	Start-up time a few minutes. Not dimmable. Reasonable efficacy. High light output per lamp. Colour change possible at end of useful life.	Suitable for lighting objects (shop window displays) or as general downlighting in high-ceilinged rooms.
Low-pressure sodium lamps	Very high efficacy. Monochromatic light, no colour rendering. 120–200 lm/W with lamp life of 10 000 to 16 000 h. Zero CRI and very low CCT.	Low-cost outdoor lighting for applications where colour rendering is not required.
High-pressure mercury vapour lamps	Low- to mid-efficacy lamps covering a broad lumen-package range. Poor to moderate CRI and relatively long warm-up periods. 23–60lm/W with lamp life of 6 000 to 28 000 h. Low- to mid-range CRI and CCT.	Mostly used for street, security and industrial lighting. Low first costs but uneconomic over the lamp life cycle compared to equivalent alternatives.
Self-ballasted nonblended Mercury vapour lamps	Very low to low-efficacy lamps covering a broad lumen-package range. Poor to moderate CRI and relatively long warm-up periods. 14–29 lm/W with lamp life of 6 000–12 000 h. Mid-range CRI and CCT.	Mostly used for street, security and industrial lighting in non-OECD countries. Very low first costs but highly uneconomic over the lamp life cycle compared to equivalent alternatives.
Compact Fluorescent Lamps, modular (external ballasts)	Compact lamp with high efficacy. Longer life and slightly higher efficacy than equivalent ballast-integrated CFLs. Dimmable when used with specially designed electronic ballasts. 60–80 lm/W with lamp life of 10 000 to 20 000 h. High CRI and broad range of CCT available.	Alternative to incandescent lamps (more efficient), but with (external ballasts) electronic ballasts.

Source: Adapted and updated from CADET Energy Efficiency, 1995.

Abbreviations: CCT = colour correlated temperature; CRI = colour rendering index;

Tab. 2. Summary of lamp characteristics

3.1.2 LED in the lighting

The lighting concept is changing: in particular, more attention to energy savings policies and to more comfort for users are the new main aims. In order to meet a so complex scenario, luminaries and lighting control system had to increase their performances. Specifically, with regard to the luminaries, the performance of the lamps are became a very important goal.

In this research context LEDs (Light Emitting Diode) are becoming more and more interesting devices. In particular, the development of power LEDs is more and more an affordable solution to meet the needs of modern lighting product/system.

LEDs have reached interesting features such as (Liu, et al., 2009.):

- high luminous efficiency now a days (at least 90-100lm/W);
- lower losses in the distribution of the controlled luminous flux compared to traditional lamps (emitting only a beam of 120°, whilst traditional have about 360°);
- extremely small dimensions and consequently extreme flexibility of use;

- good colour rendition (Colour Rendering Index, CRI \geq 80);
- wide range of colour temperature;
- light-up instantaneously;
- fully dimmable without colour variation;
- coloured light without filters;
- dynamic colour control.

But this new lamp compared to traditional ones has a very high initial cost. Its use today is not so advantageous in all applications, but only in specific situations where the particular characteristics of the LEDs (small size, light coloured or dynamic) are really useful.

Specific areas of virtuous application of these new lamps can be identified in two broad categories, relating to the creation of performance luminaries in a position to communicate with right control systems for the management of lighting contributions and of special optical system, ad hoc, with high lighting performance and small sizes (Liu, et al., 2009).

Concluding, with regard the use of this innovative lighting source, small, efficient and dynamic (colour management, the luminous flux, et.), its application is already introducing benefits in some specific areas (such as implementation of lighting performance able to can communicate with the management daylight systems and implementation of optical systems with high lighting performances and small size). Indeed, about future prospective, considering the technological growth perspectives of this lighting source in the coming years, and its positive results provided over a relatively short time since it came into the light design, in the short- medium-term, its use may be extended to the more traditional areas of illumination.

3.1.3 O-LED in the lighting: some notes and prospective

The innovation of technology, electronics and “solid-state light” will be protagonist in the next future: LEDs and O-LEDs (Organic Light Emitting Diode).

Regarding OLEDs, their technology is similar to that of LEDs, the only difference is that the semiconductor used is not inorganic (silicon) but organic (carbon).

Regarding lighting sector, today LEDs are already used in opposite OLED, are not lighting system, but they are only prototypes. They have not yet high performance in order to be on market.

Today, they limits are:

- low efficiency (23lm/W white light 63lm/W green light);
- maximum size of 50cm²;
- very high expensive (300€ for a device of 20cm²);
- the time life is not very long 10.000h (50% of initial luminous flux).

But this should be only a momentary situation. In fact, the potential of OLEDs are undoubtedly vast, especially considering their particular shape.

In fact, they will be not lighting sources to put in luminaries, but they will be large lighting areas (e.g. they could be walls and ceilings which will be able to produce diffused, dynamic and variable colour light). They aren't rigid but flexible, they could be opaque or transparent of various forms which will be able to produce white or coloured light, static or dynamic images.

They will be large lighting areas with low luminance and high luminous efficiency, characterized by soft and diffused light.

Besides, OLEDs, once reached the optimal performance, could be more advantageous than LEDs for:

- lower luminance (no problems with glare);
- no heat (no problem with dissipation);
- spectral emission more rich, Fig. 3. (High CR).

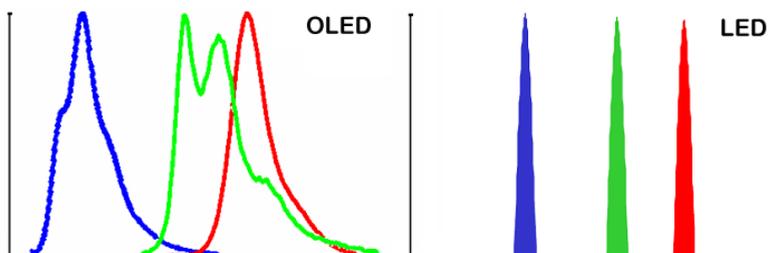


Fig. 3. Spectral emission of OLED and LED (Philips presentation, 2009)

As mentioned, the major current limitations of OLEDs technology, besides cost, are the small size, low luminous efficiency and time life. The following (Fig. 4) charts show, however, as within a short period, 7/8 years (fig.4), those constraints should be overcome, thanks to worldwide and European funding which are allocated to encourage the development of this new technology (eg. projects Olla, Oled100 or TOPLESS).

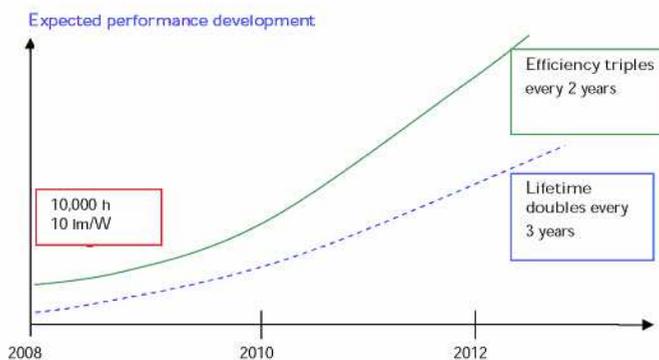


Fig. 4. Expected performance development of OLEDs (Philips presentation, 2009)

The research project OLLA consortium of European companies and universities, which began Oct. 1. 2004 and completed in 2008, was based to produce O-white LED emission and high efficiency lighting to use (60 lm/W, this objective has been achieved in the laboratory). The project Oled100 begins by major successes of OLLA and it has its benchmark, the new international agreement on environmental protection of the European Community. It is called "Packet 20-20-20" which also imposes a 20% reduction in CO emissions within 2020. Oled100's aim is a more durable product with better light and more handsome:

- better light efficiency (100 lm/W);
- longer life (100.000 h);
- increased emitting area (100×100 cm²);
- lower cost (100 €/m²);
- standardization system.

Regarding price reduction of OLEDs, today there are another OLED project called TOPLESS (Thin Organic Polymeric Light Emitting Semiconductor Surfaces). It is focusing on commercially viable lighting products.

Concluding OLEDs have achieved interesting results in display applications, but they are not yet competitive in functional lighting.

However the research is moving in this particular sector, on different fronts in order to have a common aim of efficient technology and in the same time competitive about price.

In particular, it is trying either to improve lighting performance of OLED (efficiency, luminance, and life time) or to pay attention to reducing costs (regarding choice of materials, cost of packaging and production process).

Considering the projected development trends of the largest manufacturers Osram, Philips, Siemens and GE and the speed with this technology is developed the achieve of interesting performance appears really near.

3.2 Intelligent management systems: from ballast to building automation system

Modern lighting use intelligent management systems, which, if properly integrated, can provide attractive energy savings.

Specifically, there are different lighting control devices, which according to the application layer, capable of handling functions more and more complex in efficient way.

These technologies can be summarized in the following three levels:

- *First level:* the single lamp manager. The most common is ballast, used by all discharge lamps.
- *Second level:* lighting control system. It coordinates of all elements of the lighting system based on specific criteria;
- *Third level:* domotic and building automation system. They manage the last level: it coordinates synergistically all plants present in a building/dwelling.

Considering the importance of these devices, each of these technologies will be analyzed in the following paragraphs.

3.2.1 Single lamp manager

In the lighting sector, the main lamp manager is ballast; it is a device that primarily allows the working of discharge lamps. In fact, discharge lamps cannot be connected directly to the supply line, because, to ignite them it is necessary to provide an extra voltage of some kV. In order to limit the current, a ballast in series with the lamp is typically used. Today there are electro-mechanical ballast and electronic ballast, new generation device.

Today, all new generation luminaires are fitted with electronic ballast.

This is because, besides the simple operation of discharge lamps, electronic ballast, compared to electro-mechanical ballast, device has other main advantages, such as:

- to regulate luminous flux;
- to extend lamp life;
- to maintain constant the luminaires' luminous flux.

So, all these factors ensure comfort, energy savings and safety.

In order to better assess the benefits provided by this device is shown comparative analysis of the performances of a 150W HPS (High Pressure Sodium) street luminaire, made by Department of Energy of the Politecnico di Milano, in 2010 (Dolara et al. 2010). The comparative analysis is made supplying the same lamp with an electro-mechanical traditional power supply system (comprehensive of ballast and capacitor) and successively with an electronic ballast.

In summary, the comparison made shows that:

- electronic ballast can perform luminous flux regulation: this is very important in order to save energy. In fact, a reduction of the luminous flux of 30%, in the period from 24.00 to 8.00, as required by the guidelines for light pollution (UNI 11248, 2007 and L.R. n°17, 2000), may result in an average reduction of energy consumption of about 30%;
- electronic ballast ensures lamps greater useful life. This allows a reduction of maintenance costs and an increase road safety;
- electronic ballast allows to maintain constant the luminaires' luminous flux for all the working period: changing the main voltage, the illuminance is constant. It's very important specially in street lighting sector because the RMS voltage value, supplied by mains electricity distribution, varies during a day. In this way the parameters of the lighting design and drivers' safety can be also guaranteed for all the working period of the lighting. Finally, maintain constant the voltage, so the power consumption, allows to save 25% of energy compared to a electro-mechanical ballast. Considering this factor, it is interesting to know that supply voltage is always higher than the nominal voltage of 230 V during any day of the year when the street luminaires have to be powered;
- finally, to maintain constant the voltage prevents shutdown of the lamp due to a sharp decrease of the RMS value of voltage supply;
- electronic ballast reduce PQ problems and allows a rational use of the lighting reducing line losses, voltage drop and voltage distortion (electronic ballast can implement the compensation of all the non-active power components. The input current waveform of electronic ballast is mainly a sinusoid in phase with the voltage waveform and the power factor is very close to the fundamental power factor, that is just a little less of unity).

Concluding, for energy savings, these considerations are very interesting for the field of street lighting, considering the amount of energy used for this application and the obsolescence of luminaries in it used (as said, only the replacement of the old electro-mechanical ballast with new electronic ballast could provide an average savings of about 30%), but they are also extensible to all applications that use discharge lamps (offices, industry, commercial buildings etc.).

Further more, all these characteristics have been in general easily implemented in LED power supply.

3.2.2 Lighting control system

A lighting control system is a device that manages the operation of the lighting according to specific criteria. These devices, combined with the choice of efficient lamps and luminaries characterized by high LOR (Luminaire Output Ratio), can provide significant energy savings (IEA, 2006).

Currently there are a few common strategies within the lighting control technique. According to different lighting sector, outdoor (in particular street lighting) or indoor (office), there are specific lighting control system.

Outdoor lighting system (for street lighting):

- *intelligent systems* allow for individual street luminaries to automatically react to external conditions such as traffic density, daylight levels, road works, accidents, or weather circumstances. Thanks to these devices, the parameters of the lighting design and drivers' safety can be also guaranteed for all the working period of the lighting;
- *remote monitoring* devices on each luminaries of the street lighting allow the operator to collect real-time data on system performance at the fixture level. In this way the

operator is able to savings and performance of the luminaries, and optimizing equipment maintenance.

Indoor lighting system (Benediktsson, 2009):

- *occupancy sensing* is intended to limit the use of artificial lighting when the area is not occupied;
- *daylight harvesting* uses a measurement of available daylight to reduce the use of artificial light sources, usually by dimming them;
- *time scheduling* can vary the lights based on some time schedule and the task tuning can alter the light scenes in a room based on the current activity;
- *personal control* devices allow users to control their personal light, from their own panel or even from their computers;
- *variable load shedding* can be useful in circumstances where some predefined energy maximum is to be avoided (is not as common).

Concluding all this type of device provides high energy savings equal to 54% (IEA, 2006) because, with these systems, artificial light is provided only when needed and with right lighting levels.

3.2.3 Domotics and building automation system

The term “Domotics” is commonly used to designate a practice of increased automation of housing environments to obtain high comfort and safety for final-users with lower power consumption. In fact the main aim of “Domotic” is the intelligent cooperation of several different equipments to manage the housing environments in an efficient, safe and comfortable way. When instead, this practice is applied to buildings it’s called Building Automation.

The systems for the integrated management of all technology functions of a building are generically called Building Management Systems (BMS). They manage control systems for lighting, shading, air conditioning, access and security. In particular, for lighting systems, the most common standard protocol, used by the BMS, is the DALI (Digital Addressable Lighting Interface).

Talking about interaction between different equipment of a building, with regard to lighting, the equipment that must mainly cooperate, through a BMS, are the lighting, the air conditioning and the shading to obtain efficient and comfortable solution.

Then, as regards the management of the lighting system, the use of fully or partially automated systems for control and integration of artificial and natural light can contribute to the determination of certain benefits. They are: increased visual and thermal comfort inside buildings, obtaining energy savings due to lower consumption of electricity for lighting and, in the case of air-conditioned buildings, a reduction of thermal loads generated by endogenous sources of light.

But, it’s important to use efficient control system for daylighting and for shading devices to optimize this particular type of synergy.

Concluding, today Building Automation Systems to control lighting can concur to energy savings. Besides this, they provide other benefits: the ability to track occupancy and energy use, the ability to monitor and control lighting throughout a large facility, and the ability to minimize peak demand.

3.2.4 Daylighting

Daylighting systems are a series of devices capable of delivering or managing the natural light inside the indoors environments. To make it, these elements must be integrated or

added the openings of the building. *The resulting combination of the windows and these equipped elements is called "Daylighting Systems"* (Sabry, 2006).

There are many kinds of these devices, for example elements adjacent to windows or integrated into their glass panel (they are repetitive planar arrangement of tiny optical devices), reflectors or light shelves (these are systems made of reflectors positioned on either the interior or the exterior part of the windows) etc.. Each one of these systems has different characteristics related to major performance parameters. For this reason, it is important to choose them according to visual performance and comfort, building energy use and systems integration.

Also, being daylight, for its nature, a light source that varies constantly in intensity, colour and luminance distribution, in all indoor environments it is necessary to implement the natural light with an electric lighting system to ensure adequate lighting levels to support any visual tasks even during all day. So, the electric lights serve to balance the available daylight and to create a dynamic luminous environment.

Then, it is important that the total lighting system (natural and artificial lighting) meets daylighting controls system (better if it is automated) in order to fully benefit from natural light and to save energy.

In fact, regarding the energy savings, a recent study (De Carli, De Giuli, 2009) has shown that the correct integration of natural light, through the use of automatic daylighting system and BMS system, can reduce building energy consumption. Specifically, this study analyzed energy savings obtained by different lighting and shading control strategies, the dynamic daylight performance parameters and the annual illuminance profiles of a sample office, located in five different latitudes: Stockholm (59°65' N), Venice (45°50' N), El Cairo (30°13' N), Bombay (19°12' N) and Colombo (6°82' N). Reducing consumption was from 31% to 73%, according to latitude. Therefore a significant saving in all cases.

Moreover, as already shown by many studies, the natural light provides for functioning of our body, our mental well-being and to increase our productivity at work. Therefore, it is very important to have interiors characterized by a good natural lighting. Again the daylighting is a great tool.

Concluding, daylighting is able to support health and activities of people and is able to reduce energy demand in the building. But, in order to do this, it must be managed by Automation Building System characterized by automatic lighting and automatic daylighting system.

4. Case studies. Flexible LED light sources

LEDs are growing and increasingly widespread technology. To appreciate some of their qualities, in this section will present three case studies of lighting using LED and the relative advantages of this practice.

4.1 Office

In this case study will be illustrated lighting design realized by LED solutions of an Edison's headquarter office, in Milan. It was designed by the authors.

In particular, this case study shows the possibility to reduce energy consumption and to increase the visual and environmental comfort through LED solutions, integration of natural light and control lighting systems.

Introduction

In the past, in this office there were 9 traditional luminaires with fluorescent lamps without any lighting control system, although there are 4 big windows (fig. 5). The luminaires gave a

very high average illuminance, equal to 800lx in opposite the (level required from the European Standard is equal to 500lx (UNI 12464-1).



Fig. 5. Old lighting system with fluorescent lamps

Design

In the new project, the 9 luminaries, with 4 fluorescent tubes to 18W each-one, were replaced with 8 polycarbonate lighting panels (Lumisheet, 37W, Fawoo). This polymer layer is characterized by a texture able to extract and restore the environment providing the lumen output with drowned coast LEDs, with an excellent performance. Also, an automatic control system (characterised by natural light sensors for detection and by dimming) was used (Fig. 6).

Results

The new system, without control system, can provide 500lx ensuring energy saving of 58%. Moreover this savings increases to 70%, if, as requested by the client, the value of average illuminance is decreased to 350lx. With automatic control system and average illuminance to 350lx the energy saving grow up to 84%.

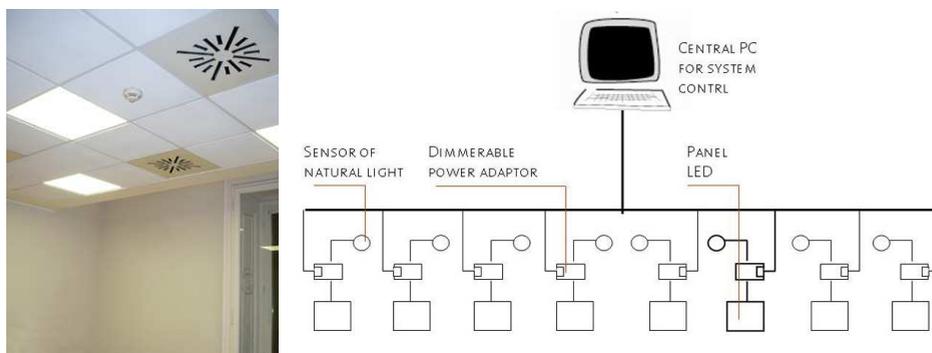


Fig. 6. New lighting system with LED panel and schema of the lighting control system

Conclusion

The choice of this particular LED technology has enabled to reduce the installed power, to avoid glaring problems and to manage easily artificial light.

Finally, the control system has allowed to optimize energy savings, to integrate the natural light, so increasing the visual and environmental comfort for workers.

4.2 Historical building

In this case study the lighting system refurbishment of a living room in an historical building of Edison, in Milan, will be described. It was designed by the author (Faranda et al. 2010).

In particular, this case study shows the possibility to reduce energy consumption, and to increase the visual and environmental comfort through LED solutions, integration of natural light and control lighting systems. Moreover, it shows the application flexibility of the LED light source in the production of new high performance luminaires

Introduction

The area of intervention, is defined by a particular architecture and characterized by a very long and narrow plan, from a historical glass vault, and with large windows.

The current lighting of the room is composed by fluorescent lamps both for the back-lighting of the vault and for the desks area, for a total installed power of 19.3kW.

There is no lighting control system, although there are large windows.

Regarding the lighting performance, it provides a very low average level of illuminance equal to 135lx (even if the level required from the European Standard is equal to 500lx (UNI 12464-1)).

Also, the analysis of the technical query performed of the architectural structure showed hazard conditions of the glazing system covering the vault (Fig. 7).



Fig. 7. Actual condition of the vault and back lighting vault (luminaries with fluorescent lamp)

Design

In order to resolve the problems about the low lighting performance and put in safety the vault, the existing windows are been replaced with 552 polycarbonate lighting panels (Lumisheet, 21W, Fawoo). This polymer layer is characterized by a texture able to extract and restore the environment providing the lumen output with drowned coast LEDs, with an excellent performance. Moreover, to implement the levels of illuminance on the work plans have been proposed 30 luminaries with fluorescent lamps to 49W (Fig. 8). What this type of

lighting, total power installed is equal to 16kW and the average illuminance is equal to 350 lx, as required by the client.

For lighting management was provided a control system with sensors for detection of natural light and dimming devices.

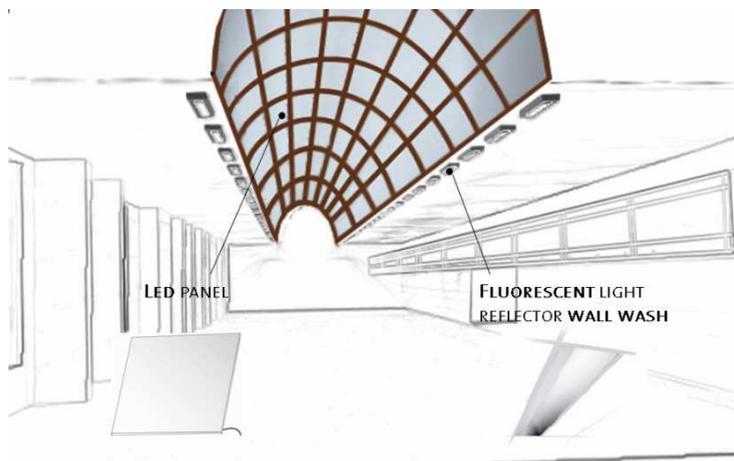


Fig. 8. New lighting concept of the room

Conclusion

The proposed lighting system, due to the efficiency of the luminaries and to the integration of the light management system, can meet the requirements of the standard (UNI 12464-1), to achieve significant energy savings of about 66% and a reduction of total costs, for use and management, of about 70%. The increased lighting characteristics associated with the integration of daylight also enhance comfort and environmental well-being for users who work every day in the room.

Finally, the specificities of the light panels solution, only achievable for obvious dimensional features with LEDs sources, allows the safety and upgrading of the vault through the strict respect for the historical identity of the place.

This case, although it is not common, is very important in the countries with a lot of historical buildings.

4.3 Particular application

In this case will be presented the idea of a LED lighting system realized for the box of WSB Team Yamaha Sterilgarda designed by the authors. In particular this analysis shows the possibility of increasing the visual and environmental comfort through the use of LED.

Introduction

Today, the lighting system used in these areas is generally characterized by spotlights with halogen (low efficiency light source with high luminance and high spectral infrared emission), positioned on the supporting structures of the American box (Fig. 9).

This type of solution has two problems: direct/indirect dazzling for operators and heat.

The mechanics work in order to avoid this problem pointing the spots towards the cover of the box. However, this solution generates very low results as regards illumination levels guaranteed average illuminance of 100lx to h.60cm.



Fig. 9. Old lighting system of the box Yamaha, alogen spots (Photo agency: Alex Photo)

Finally, this type of lighting creates reflections on the phenomena for the body of motorbike and on the walls of the box on the shiny sheet, during photo and television shoots.

Project

In the planning in order to avoid the problem of the dazzling, it was decided to use a lighting diffuse system. Instead were chosen LED devices (panels with LED drowned coast) in order to avoid the problem of heat.



Fig. 10. New lighting system on the box Yamaha, with LED panel (Photo agency: Alex Photo)

Specifically, the lighting system, shown in Fig. 10, was characterized by: 24 LED panels (Lumisheet, 21W, Fawoo) drawn to each other and arranged in two sections of the ceiling, 4 linear suspension elements LED (Linealuce, 37W, Maytag) and 4 LED projectors (Miniwoody, iGuzzini) as.

Results

This system has resulted in:

- optimal lighting levels for activities equal to 1000lx at h.60cm ca;
- excellent uniformity 0.8;
- pleasant environment (CRI LED > 90);
- a low consume of energy (installed capacity 667W, approximately 15% less than the one installed in the old system);
- easy and immediate installation (panels extremely manageable, 60x70x0.8cm 5.2kg/each one directly supplied by a simple plug).

Conclusions

The choice to use a particular type of lighting with LED technology has improved dramatically lighting performance guaranteed (average illumination from 100lx to 1000lx at h.60cm) and to improve workers' visual, environmental comfort and reducing energy consumption.

Whereas, the modular system and the simplicity of power supply have made the solution effective both to installation/operation and to storage/transportation.

Finally, about image, the proposed solution is successful. In fact, the his atypical appearance, compared to lighting of other teams, has become a distinctive and characteristic element for the box.

5. Conclusion

Scenarios which characterize the lighting design are nowadays becoming increasingly complex because alongside the technical/functional needs, the comfort condition, user's well being and saving energy have now priority.

The need to find new technological solutions, new languages for lighting systems is witnessed by numerous research projects aimed at studying sophisticated control systems (eg. BMS) and new sources of illumination. Especially and specifically for light source, it is significant the special care with which it is supporting the study and development of power LEDs and OLEDs. The advent of OLEDs technology, in particular, will lead to a conceptual revolution of the light source: cannot longer three dimensional but two dimensional, no single lighting elements point but big lighting sources surface could indeed illuminating, in the near future, our environments.

In conclusion, today there are already useful technologies to achieve important energy savings and at the same time to increase the comfort for users. Then, many other devices are developing. Therefore, the efficient tools are there, we just need to learn to integrate them in our traditional contexts.

6. References

- G. Benediktsson (2009), *Lighting Control- possibilities in cost and energy-efficient lighting control techniques*, IEA, LTH, December 2009.
- L. Blaso, A. Pellegrino, (2007), *Sistemi di controllo ed integrazione luce naturale ed artificiale: stato dell'arte e presentazione di un'attività di ricerca sperimentale*, *www.infobuilddossier.it*, 29. July, 2007.
- P.R. Boyce, J.A. Veitch, G.R. Newsham, M. Myer, C. Hunter (2003), *Lighting Quality and Office Work: A Field Simulation Study*, 2003.
- M. De Carli, V. De Giuli (2009), *Optimization of daylight in buildings to save energy and to improve visual comfort: analysis in different latitudes*, *Eleventh International IBPSA Conference Glasgow, Scotland, 27-30, July 2009*.

- A. Dolara, R. Faranda, S. Guzzetti, S. Leva (2010), Power Quality in Public Lighting System, Proc. 14th International conference on Harmonics and Quality of Power, 26-29 Sept. 2010.
- M. D. Egan (2002), *Architectural Lighting*, New York: McGraw-Hill, 2002.
- E-Street, Project Report - Intelligent Road and Street Lighting in Europe, E-Street
- R. Faranda, S. Guzzetti, S. Leva (2010), LEDs Lighting: Two case studies, U.P.B. Sci. Bull. series C, to be published
- A.G.A Gregorius, H. Siti (2007), LED Technology in Architectural Lighting of Building's Façade, *Proceeding 10th Int'l QIR*, 4-6 Dec. 2007.
- IESNA (2000), *IESNA Lighting Handbook*, 9th Edition Illuminating Engineering Society, 01-Dec. 2000.
- International Energy Agency (2006), *Light's Labour's Lost*, Policies for Energy-efficient Lighting, 2006.
- T. Liu, F. Yang, J. Yu, Y. Wang (2009), Designing of LED Illuminating System and Testing Notice, *Proc. WASE International Conference on Information Engineering*, Taiyuan, Shanxi, China, Vol. 2, 10-11 Jul 2009, pg. 277-280
- L.R. n°17 (2000), Misura urgente in tema di risparmio energetico ad uso di illuminazione esterna e di lotta all'inquinamento luminoso, *L.R. n°17*, Mar. 2000.
- NYSERDA (2002), New York State Energy Research and Development Authority, *How-to guide to Effective Energy-Efficient Street Lighting*, Oct. 2002.
- OECD/IAC (2006), Light's labour's lost, Policies for Energy-efficient Lighting, 2006.
- OECD/IEA (2010), Phase out of incandescent lamps, Implications for international supply and demand for regulatory compliant lamps, pg.9, 2010.
- M. Pizzagalli (2009), *Domotica per una illuminazione di design*, la Casa Futura vista dalla fondazione Politecnico di Milano, Casa future, Apr. 2009.
- Philips presentation (2009), OLED Lighting innovation 2009, Politecnico di Milano, 4 Nov. 2009.
- Price list Philips (2009), *Price list Philips lamps and accessories*, 2009.
- Eurelectric (2004), *Proceeding of annual conference of Eurelectric 2004*, 2004.
- H. M. K. Sabry (2006), The Impact of Daylighting- Guiding Systems on Indoor Natural Light Penetration: Simulation Analysis for Light-Shelves, PLEA2006 - *The 23rd Conference on Passive and Low Energy Architecture*, Geneva, Switzerland, 6-8 Sept. 2006.
- P. Spotti (2009), Punta della Dogana: un museo elettronico, *Luce&design*, pg. 29-36, Nov. 2009.
- Standard EN 15193 (2007), *Energy performance of buildings - Energy requirements for lighting - Part 1: Lighting energy estimation*, Mar. 2007.
- Standard DIN IEC 60294 (1986), Measurement of the dimensions of a cylindrical component having two axial terminations, Gen. 1986.
- Standard IEC 62442 (2007), Energy efficiency of electrical lighting equipment, International Standards Commission, 2007.
- Standard UNI EN 11248 (2007), *Illuminazione stradale. Selezione delle categorie illuminotecniche*, Oct. 2007.
- Standard UNI EN 12464-1 (2004), *Luce e illuminazione - Illuminazione dei posti di lavoro - Parte 1: Posti di lavoro in interni*, Oct. 2004.
- Standard UNI EN 13201-1 (2003), *Illuminazione pubblica - Parte 1: selezione delle classi di illuminazione*, Apr. 2003.
- J.A. Veitch, G.R. Newsham, (1996), Determinants of Lighting Quality II: Research and Recommendations, *Lighting Research & Recommendations*, National Research Council of Canada, 104th Annual Convention of the American Psychological Association, Canada, ED408543, Aug. 1996.
- www.clintonfoundation.org; www.infobuild dossier.it



Paths to Sustainable Energy

Edited by Dr Artie Ng

ISBN 978-953-307-401-6

Hard cover, 664 pages

Publisher InTech

Published online 30, November, 2010

Published in print edition November, 2010

The world's reliance on existing sources of energy and their associated detrimental impacts on the environment- whether related to poor air or water quality or scarcity, impacts on sensitive ecosystems and forests and land use - have been well documented and articulated over the last three decades. What is needed by the world is a set of credible energy solutions that would lead us to a balance between economic growth and a sustainable environment. This book provides an open platform to establish and share knowledge developed by scholars, scientists and engineers from all over the world about various viable paths to a future of sustainable energy. It has collected a number of intellectually stimulating articles that address issues ranging from public policy formulation to technological innovations for enhancing the development of sustainable energy systems. It will appeal to stakeholders seeking guidance to pursue the paths to sustainable energy.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Stefania Guzzetti, Roberto Faranda and Sonia Leva (2010). Design and Technology for Efficient Lighting System, Paths to Sustainable Energy, Dr Artie Ng (Ed.), ISBN: 978-953-307-401-6, InTech, Available from: <http://www.intechopen.com/books/paths-to-sustainable-energy/design-and-technology-for-efficient-lighting>

INTECH

open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2010 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](#), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.