

## 13 Summary and conclusions

Lighting is a large and rapidly growing source of energy demand and greenhouse gas emissions. At the same time the savings potential of lighting energy is high even with the current technology, and there are new energy efficient lighting technologies coming on the market.

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Currently, more than 33 billion lamps operate worldwide, consuming more than 2650 TWh of energy annually, which is 19% of global electricity consumption. The total lighting-related carbon dioxide (CO<sub>2</sub>) emissions were estimated to be 1900 million tons in 2005, which was about 7% of the total global CO<sub>2</sub> emissions from the consumption and flaring of fossil fuels. The global electricity consumption for lighting is distributed approximately 28% to the residential sector, 48% to the service sector, 16% to the industrial sector, and 8% to street and other lighting. In the industrialized countries, national electricity consumption for lighting ranges from 5% to 15%, on the other hand, in developing countries the value can be even higher than 80% of the total electricity usage.

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More than one quarter of the world's population is still without access to electric networks and uses fuel-based lighting to fulfil its lighting needs. The fuel-based light sources include candles, oil lamps, kerosene lamps, biogas lamps, propane lamps, and resin-soaked twigs. While electrification is increasing in the developing countries, it is more and more important to adopt energy efficient light sources and lighting systems both in the developing and industrialised countries. Solid-state lighting combined with renewable energy sources has already reached some remote villages in developing countries, where it brings affordable, safe, healthy, and energy efficient lighting to the people.

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The amount of consumption of light in the world has constantly been increasing. The amount of global consumption of light in 2005 was 134.7 petalumen hours (Plmh). The average annual per capita light consumption of people with access to electricity is 27.6 Mlmh, whereas the people without access to electricity use only 50 klmh.

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Any attempt to develop an energy efficient lighting strategy should, as the first priority, guarantee that the quality of the luminous environment is as high as possible. The results presented in this Guidebook demonstrate that this is achievable, even with high savings in electricity consumption. Through professional lighting design energy efficient and high quality lighting can be reached. Better lighting quality does not necessarily mean higher consumption of energy. While it is important to provide adequate light levels for ensuring optimized visual performance, there are always light levels above which a further increase in the light level does not improve performance.

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The increased possibilities to control both the intensity and spectrum of light sources should allow the creation of more appropriate and comfortable luminous environments. Also, the use of lighting control systems, based on presence detection and the integration of electrical savings. New technologies such as LEDs offer high flexibility in the control of light spectra and intensities, which enhance their attractiveness besides their growing luminous efficiency.

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It is important to search for technological lighting solutions which meet human needs with the lowest impact on the environment during their life cycle. The environmental impacts of lighting include production, operation and disposal of lamps and related materials. The total lighting energy used depends, in addition to the used lighting equipment (lamps, ballasts, drivers, luminaires, control devices), also on the lighting design and the room characteristics.

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There are several characteristics that need to be considered when choosing the lamp. These include e.g. luminous efficacy (lm/W), lamp life (hours), spectrum and other color characteristics (CRI, CCT), dimming characteristics and the effects of ambient circumstances on the lamp performance. Concerning all lamp types, the best lamp, if coupled with poor or incompatible luminaire, ballast or driver, loses most of its advantages.

It is foreseen that LEDs will revolutionize the lighting practices and market in the near future. The benefits of LEDs are their long lifetime, color-mixing possibilities, spectrum, design flexibility and small size, easy control, and dimming. For LEDs huge technological development is expected to continue. According to US DOE, the maximum luminous efficacy of phosphor converted cool-white LEDs is expected to be around 200 lm/W by 2015, while the luminous efficacy of warm white LEDs is expected to be above 140 lm/W. The given values are for high-power LEDs with 1 mm<sup>2</sup> chip size at a 350 mA drive current at 25°C ambient temperature without driver losses. The special features of LEDs provide luminaire manufacturers to develop new type of luminaires and designers to adopt totally new lighting practices. The key success factor for the broad penetration of general lighting market by LEDs is a light source with high system efficacy and high quality at moderate prices. One barrier to the broad penetration of the market by LED applications is the lack of industrial standards.

Currently, there is a global trend to phase out inefficient light sources from the market through legislation and voluntary measures. Two EU regulations for lighting equipment entered into force in April 2009 and they will result in gradual phasing out of e.g. incandescent, mercury and certain inefficient fluorescent and HID lamps from the EU market. Similar legislative actions are carried around the world: Australia has banned the importation of incandescent lamps from February 2009, and USA has enacted the Energy Independence and Security Act of 2007 that phases out incandescent lamps in 2012-2014. Also other countries and regions have banned, are on their way to ban, or are considering to ban inefficient light sources.

Innovative and efficient lighting technology is already available on the market; very often, however, the current installations are dominated by inefficient technology that does not utilize control systems, sensors, or efficient light sources. Today, 70% of the lighting energy is consumed by inefficient lamps. Low retrofitting rates in the building sector (and thus also in lighting installations) are the main barrier to the market penetration of adequate and modern lighting technologies. It is estimated that 90% of all buildings are more than 20 years old, and 70-80% are older than 30 years. In order to increase the knowledge and use of energy efficient lighting, it is essential to increase dissemination and education, as well as to get new standards and legislation.

Energy efficient lighting also includes considerations of the control of light and the use of daylight. A sustainable lighting solution includes an intelligent concept, high quality and energy efficient lighting equipment suitable for the application, and proper controls and maintenance. Further energy savings can be achieved with smart lighting control strategies. Today, the most common form of control (the standard wall switch) is being replaced by automatic components which are based on occupancy or daylight harvesting. Examples of this technology are occupancy sensors which turn the lights off when the area is unoccupied, time-based controls and the dimmer plus photocell combination. These can lead to energy savings that vary from 10% with a simple clock to more than 60% with a total integrated solution (occupancy plus daylight plus HVAC).

For economic evaluation of different lighting solutions, a life cycle cost analysis has to be made. Usually, only the initial (investment) costs are taken into account. People are not aware of the variable costs, which include energy costs, lamp replacement costs, cleaning

and repair costs. In commercial buildings very often the variable costs are paid by others who rent the flat, and the initial (investment) costs are usually paid by the investor who makes the system decisions. The energy costs of a lighting installation during the whole life cycle are very often the largest part of the whole life cycle costs. It is essential that in future lighting design practice, maintenance schedules and life cycle costs will become as natural as e.g. illuminance calculations already are.

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The aim of an optimum lighting design is to achieve certain appearances and, at the same time, to fulfill the fundamental physiological and psychological visual requirements and to ultimately put the whole thing into effect in an energy efficient manner. LEDs allow for completely new designs and architectures for lighting solutions, thus opening a new and wide field of creativity for all lighting professionals. At the same time, some old rules and standards for a good lighting design are no more applicable to LEDs (e.g. glare assessment, color rendering, light distribution, etc.).

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The expert survey conducted during 2006-2007 within the Annex 45 work indicated that among the lighting community there is a lack of knowledge of the characteristics and performance of new lighting technologies. Another major topic that was raised was the lack of awareness of the total life-cycle costs. The survey also indicated resistance to the adoption of new technology.

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Commissioning is done for the number of different reasons: clarifying building system performance requirements set by the owner, auditing different judgments and actions by the commissioning related parties in order to realize the performance, writing necessary and sufficient documentation, and verifying that the system enables proper operation and maintenance through functional performance testing. Commissioning should be applied through the whole life cycle of the building. The Guidebook presents an example of commissioning process applied to a lighting control system.

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Case studies of different types of lighting systems were conducted within the Annex 45 work. The studies were conducted for twenty buildings, most of which were offices and schools. In office buildings different case studies showed that it is possible to obtain both good visual quality and low installed power for lighting. In offices and schools it is possible to reach the normalized power density of  $2 \text{ W/m}^2$ ,  $100 \text{ lx}$  (even  $1.5 \text{ W/m}^2$ ,  $100 \text{ lx}$  in some office cases) with the current technology. It was found that the use of lighting control system to switch the lights on and off based on occupancy sensors can reduce the lighting energy intensity of office buildings. Additionally, the use of dimming and control sensors for the integration of daylight and artificial light can yield to further energy savings. The case studies show examples of LEDs in task, general and corridor lighting. The LED lighting requires a new approach to lighting design. The case studies show that LEDs can be used in the renovation of lighting in commercial buildings.

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In 2005 the incandescent lamps dominate the lighting sector. The total annual light consumption in residential sector is only  $3 \text{ Mlmh/person}$  and the electric energy consumption is as high as  $140 \text{ kWh/person}$ . In the commercial sector the annual light consumption is almost three times higher ( $8.9 \text{ Mlmh/person}$ ), while the energy consumption is only 35% higher than in the residential sector. This is due to the use of more efficient lighting technology in the commercial sector. Compared to 2005, it is estimated that there will be an additional light demand (light consumption by end user) of 25% by 2015, and of 55% by 2030. This will, however, be compensated by facility utilization factor (improved luminaire light output ratio and room utilization) and decreased mean operating time (improved daylight utilization and control systems).

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It is expected that the share of different light sources producing the total electrical lighting will change in the future. This is due to the development of light source technologies, the increasing scientific understanding of vision, the recommended values of illuminances have followed the development of light sources. For instance, in the second half of the 20<sup>th</sup> century the evolution of fluorescent lamps led to increases in the recommended illuminance levels. The difference between the lighting standards and recommendations in different countries has been attributed to the economical context and the geographical zone of the country. The current indoor lighting design is based largely on providing more or less uniform levels of illuminance in the room, while the perception of the luminous environment is related mainly to light reflected from surfaces i.e. luminances. Thus innovative lighting design methods could be introduced which give a high priority to the quality of the luminous environment as our eyes perceive it. Both the electrical lighting design and the use of daylight have a major impact on lighting quality and energy efficiency. The present lighting recommendations do not specify recommended values of daylight factors or other daylight parameters. This is a field where practical metrics could be developed and mentioned in the recommendations. Reduction of the size of light sources (compact HID lamps, LEDs) may lead to increased risk of glare. Standards and recommendations should be adapted accordingly. One parameter to assess the quality of lighting is the color rendering index CRI. The current CRI is not suitable to LEDs due to their peaked spectra. The CIE recommends the development of a new color rendering index (or a set of new color rendering indices), which should be applicable to all types of light sources including white LEDs. A major future development of lighting recommendations is that beyond the visual requirements they should address also the non-visual effects of light.

The evolution of standards has, at large, followed the development of lighting technologies, the increasing scientific understanding of vision, the recommended values of illuminances have followed the development of light sources. For instance, in the second half of the 20<sup>th</sup> century the evolution of fluorescent lamps led to increases in the recommended illuminance levels. The difference between the lighting standards and recommendations in different countries has been attributed to the economical context and the geographical zone of the country. The current indoor lighting design is based largely on providing more or less uniform levels of illuminance in the room, while the perception of the luminous environment is related mainly to light reflected from surfaces i.e. luminances. Thus innovative lighting design methods could be introduced which give a high priority to the quality of the luminous environment as our eyes perceive it. Both the electrical lighting design and the use of daylight have a major impact on lighting quality and energy efficiency. The present lighting recommendations do not specify recommended values of daylight factors or other daylight parameters. This is a field where practical metrics could be developed and mentioned in the recommendations. Reduction of the size of light sources (compact HID lamps, LEDs) may lead to increased risk of glare. Standards and recommendations should be adapted accordingly. One parameter to assess the quality of lighting is the color rendering index CRI. The current CRI is not suitable to LEDs due to their peaked spectra. The CIE recommends the development of a new color rendering index (or a set of new color rendering indices), which should be applicable to all types of light sources including white LEDs. A major future development of lighting recommendations is that beyond the visual requirements they should address also the non-visual effects of light.

There is a significant potential to improve energy efficiency of old and new lighting installations already with the existing technology. The energy efficiency of lighting installations can be improved with the following measures:

- the choice of lamps. Incandescent lamps should be replaced by CFLs, infrared coated tungsten halogen lamps or LEDs, mercury lamps by high-pressure sodium lamps, metal halide lamps or LEDs, and ferromagnetic ballasts by electronic ballasts;
- usage of controllable electronic ballasts with low losses;
- the lighting design. Use of efficient luminaires and localized task lighting;
- the control of light with manual dimming, presence sensors and dimming according to daylight;
- the usage of daylight;
- the use of high-efficiency LED-based lighting systems.

The Annex 45 suggests that clear international initiatives (by the IEA, EU, CIE, IEC, CEN and other legislative bodies) are taken to:

- upgrade lighting standards and recommendations
- integrate values of lighting energy density (kWh/m<sup>2</sup>, a) into building energy codes;
- monitor and regulate the quality of innovative light sources
- pursue research into fundamental human requirements for lighting (visual and non-

- visualeffectsoflight)
- stimulatetherenovationofinefficientoldlightin ginstallationsbytargetedmeasures

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