Topten Product Criteria Paper on

Light Emitting Diodes (LED's) For Non Directional Lighting

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AEA – Austrian Energy Agency

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Supported by

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Coordinated by

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Agence de l'Environnement et de la Maîtrise de l'Energie

The Project in brief

Topten is part of the international Euro-Topten Plus initiative supported by the European programme Intelligent Energy Europe and several national institutions (energy agencies, WWF, consumer associations, research institutes). On global level, Topten is coordinated by TIG, the Topten International Group. This association promotes to the Topten Charter, TIG statutes and Rules of Procedure (www.topten.eu).

Topten is a service that supports the market for energy efficient products. It aims at making energy efficient products the first choice for consumers, by offering them a user-friendly tool for product comparison and selection. The key element is an online information platform for consumers presenting the most energy efficient appliances currently available in various product categories, including household appliances, office equipment, consumer electronics and cars. Information on energy consumption and performance of products as well as several other characteristics (i.e. brand, model, price, picture) is provided. Product data is based on labels and standardized declarations as well as tests from accepted well-known institutions. The service is independent of manufacturers and retailers.

Consortium

The project is co-ordinated by the Agence de l'Environnement et de la Maitrise de l'Energie (ADEME). The other 19 project partners are:

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1 Introduction

In the EU, the total domestic lighting consumption is around 86 TWh and it is predicted to raise up to 102 TWh by 2020 (taking into account the phase out of incadescent lamps), due to an altogether growing welfare and a rapidly increasing number of lamps per home.

With the new Ecodesign regulation 244/2009/EC, a stepwise phase-out of standard incandes-cent lamp technology has been determined. Starting in fall 2009 with 100 W, lamps using incandescent technology shall gradually disappear from the market until 2012. Based on the new regulation, halogen lamps of efficiency class C will remain on the market until 2016. This class of products is about 30% more efficient than traditional incandescent lamps but much less efficient compared to CFL[1] (compact fluorescent light) and LED (light emitting diode) technology. New more energy efficient halogen lamps can serve as a temporary replacement for conventional incandescent lamps until LED technology is ready for broad application.

With the development of white LEDs, a new technology for space-efficient lighting is available. So far, however, LED lamps are scarcely used for indoor lighting in the residential sector. Market penetration is starting, although market development and quality standards are still confusing and almost non-existent. LED lamps efficiency and luminous characteristics are improving rapidly although very different LED qualities are offered in the market. Consumers are therefore unsettled by the risk of buying the wrong size or quality.

In the practical application LEDs today have reached 50 to 60 lumens per watt (equates to the level of the bulb) and a lifetime of 5–25 times that of a incandescent lamp. The quality and energy efficiency will continue to rise, even if not as rapidly as in the recent years. In the very near future, the LED light is expected to change large areas of the lighting market in a very sustainable way. Many disadvantages of the current bulbs (switch-on delay, diffuse light, electromagnetic pollution) might be overcome with LED.

This paper contains the product specification for Topten Light Emitting Diodes (LED's) for nondirectional lighting. A product should meet all criteria described in Chapter 4 in order to be listed on www.topten.eu as Best Available Technology.

In an ideal situation, criteria are based on international or European standards. In some cases widely accepted and strictly defined standards are missing – (e.g. for products in the consumer electronics segment). Within the methodology of WP3, it was intended to use the implementation measures of the Ecodesign directive as a basis for the criteria definition. The information provided in this criteria paper is therefore mainly based on

[1]Also known as Energy Saving Lamp (ESL)

the "Preparatory studies for Eco-design Requirements of EuPs – (Tender TREN/D1/40-2005) Lot 19: Domestic lighting, 2009" and on the corresponding implementing measures.

For non-directional domestic lighting the *COMMISSION REGULATION (EC) No 244/2009* has already been published in March 2009. However, for LEDs this regulation only sets minimum requirements on lamp efficiency, lumen equivalency with incandescent lamps and product information requirements. Functionality requirements for LED lamps (like lamp lifetime, switching behaviour, starting time, colour rendering, etc.) have not been included. A new EU Ecodesign Regulation "Directional lighting: luminaires, reflector lamps and LEDs" (currently in preparation) will include the missing functionality requirements and cover the remaining (LED) products like directional LED lamps (spots)[2].

The purpose of this criteria paper is to provide a common basis for the selection of criteria for the specific product group as a basis for the national website. It is a clear goal to consider the same basic criteria for products throughout the Euro-Topten network. However, the range of products differs significantly in European member States in terms of price level, configuration, energy classes and energy consumption corresponding to levels of purchasing power and behavioural aspects (mentality, customs, etc.). Consequently, specific quantitative thresholds for the individual criteria as a basis for the Topten lists may be different from country to country.

The paper starts with a short overview on the LED lamp technology currently used including some issues of efficiency and quality. It continues with a summary on current legislation and standards relevant for Euro-Topten as a basis and finally concludes with recommendations on product categorisation and criteria to be used for nondirectional lighting witch LEDs within Euro-Topten. The information given in chapters 2, 3 and 5 generally refer to LEDs. The product categorization and criteria in Chapter 4 refer exclusively to nondirectional lighting.

[2] Process is ongoing. Updated information will be given in the criteria paper for directional lighting at the en of November 2011.

2 Product Definition

This chapter provides an overview of Light Emitting Diodes (LED's). It also gives a technical analysis of the product and some background information.

2.1 Technical principle of a LED

A Light Emitting Diode (LED) is a semiconductor light source. It has the characteristics of a diode, i.e. it only allows electrical current to flow through in one direction, from the anode to the cathode, thus producing light of a specific colour. Simply put, the LED works on the reversed principle of a solar cell. Whereas the solar cell transforms (sun) light into direct current – the LED turns direct current into light.

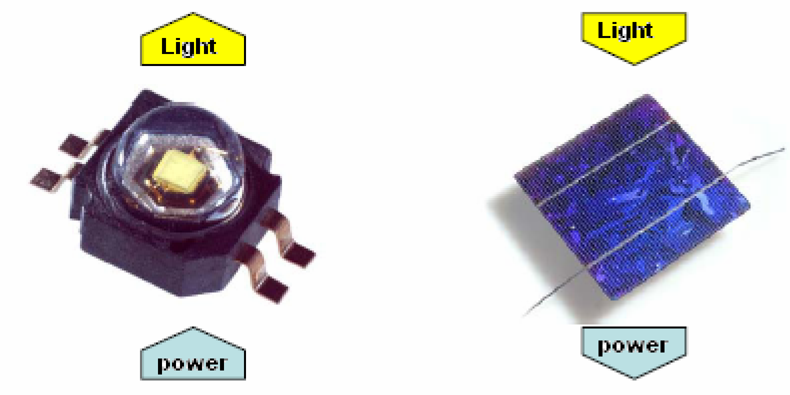

Figure 1 Principle of a LED[3]

In the early 1960ies, the red LEDs were invented and used for watches. 10 years later green and yellow LEDs came on the market. The blue LED, which is necessary for generating white light, was invented in 1995. Blue LED light is generated on the basis of the semiconductor material gallium nitride (GaN) or gallium-indium nitride (GaInN). For conversion into white light, the blue LED is coated with phosphors (eg. yellow). Depending on the concentration and color of the phosphor, different white tones can be generated.

The typical white LED chip today is 1 mm² in size, takes on an electrical power between 1 and 5 watts, and has a range from 50 to 150 lumens of visible light. The higher-wattage LEDs are realized by lining up single chips. For example, 2009 modules offered capacities of up to 100 watts.

[3] Source: Qualitätsmerkmale der LED-Beleuchtung – Aktueller Stand der Technik, Vorteile, Problempunkte und Entwicklungspotential, Bundesamt für Energie BFE, Auftragnehmer: eteam GmbH, Autor: Stefan Gasser, 1.09.2099

The maximum size is limited by the possibilities of heat dissipation. The emitted light beam of the LED does not contain any infrared components and therefore produces no heat. But the heat is produced on the back of the LED due to the warming of the semiconductor material. Temperatures above 60 degrees reduce the life time of the LED, as well as their light output. If overheated, the LEDs are destroyed.

2.2 Development trends

In recent years, the main focus in the development of LEDs has benn the field of energy efficiency. The development of energy-efficient LEDs is shown in the chart below. In the years 2003 to 2009, the efficiency of LEDs has tripled. In 2009 it reached the efficiency of the energy saving lamp. In the next 10 years a doubling of the efficiency is expected.

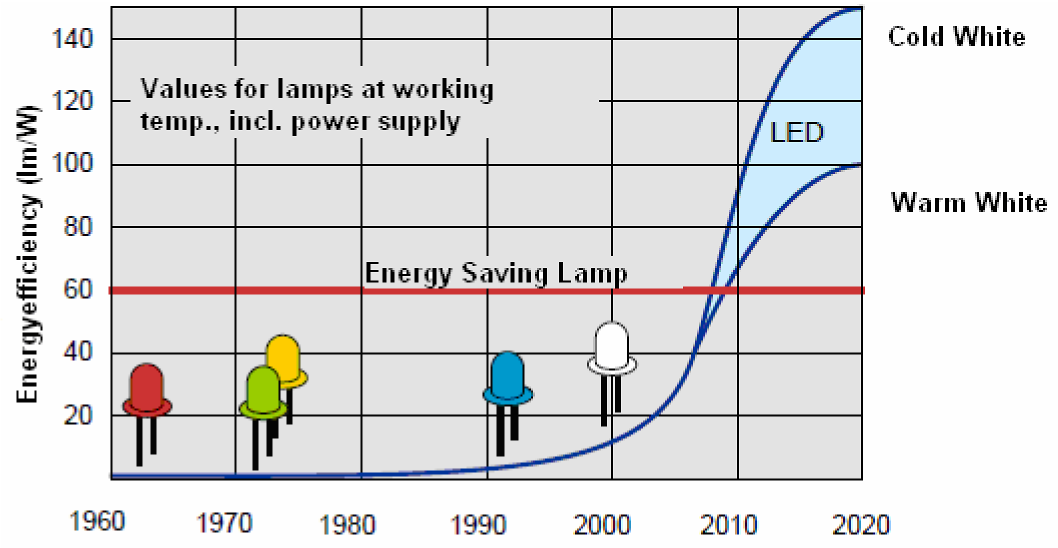

Figure 2 Development of energy efficiency[4]

In addition to the (mono-crystalline) LEDs, work on the development of organic light-emitting diodes (OLED) is ongoing as well. In the future, OLEDs could tackle the material and cost problem currently encountered in LED's. OLEDs are a flat display technology (see Figure 3) realized by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted. This technology is well suited for indoor area illumination and could appear as "glowing wall paper" without the need for luminaires.

[4] Source: Qualitätsmerkmale der LED-Beleuchtung – Aktueller Stand der Technik, Vorteile, Problempunkte und Entwicklungspotential, Bundesamt für Energie BFE, Auftragnehmer: eteam GmbH, Autor: Stefan Gasser, 1.09.2099

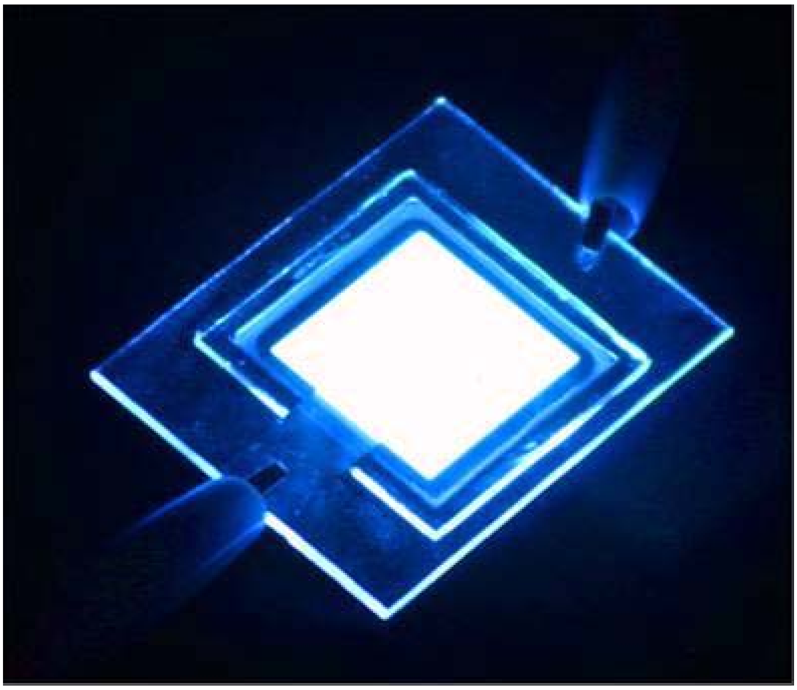

Figure 3 OLED prototype (Picture courtesy of OLLA project)[5]

OLEDs based on organic material are still part of current R&D. The first OLEDs are already on the market for particular very flat illuminated displays in portable devices, but not yet for domestic general lighting applications. The current OLEDs still have to prove their efficacy in working conditions (e.g. temperature and required life time). OLEDs are therefore classified as “Best Not Available Technology” (BNAT) and will not be considered in further chapters.

2.3 Quality criteria of LEDs

2.3.1 Key quality criteria

Three key quality characteristics are crucial for LED technology:

- **Lamp efficiency:** this is the quotient of the luminous flux[6] emitted (Φ) and the power consumed by the lamp (P_{lamp}). With values of 40 to 95 Lumen/Watt (lm/W) when in use, current LED lamps on the market are competitive with energy saving lamps. The average energy efficiency of high quality LED

[5] Source: Qualitätsmerkmale der LED-Beleuchtung – Aktueller Stand der Technik, Vorteile, Problempunkte und Entwicklungspotential, Bundesamt für Energie BFE, Auftragnehmer: eteam GmbH, Autor: Stefan Gasser, 1.09.2099

[6] ‘Luminous flux’ (Φ), which is a quantity derived from radiant flux (radiant power) by evaluating the radiation according to the spectral sensitivity of the human eye, measured after 100 hours of lamp running time.

products lies in the range of 50 to 60 lm/W. The best value measured for a product available on the market was 95 lm/W. The energy efficiency of an compact fluorescent lamp (CFL) is about 60 lm/W. Fluorescent lamps reach 100 lm/W. Experts expect the luminous efficiency of LEDs to double within the next five years. The real issue is that, at present, declaration is often poor and sometimes the declared values seem to be mere phantasms.

- **Light quality:** The quality of color is expressed through the so-called color rendering index (CRI or Ra)[7]. The best value is Ra = 100. Today's good LEDs reach a color rendering index of 80 to 95, with a continuous light spectrum (for CFL, Ra = 80 to 90). Fluorescent lamps reach an index of 80 to 90. Incandescent lamps and halogen lamps reach a maximum of 100.

- **Lamp life:** A lamp life of up to 50000 hours can only be reached if the heat dissipation is ensured and if the quality of the electronic control unit keeps up with the LED's life time. According to the experts, many of today's LED products on the market don't meet these two requirements. The life time of a LED is very difficult to determine without measurements. Realistic values given by manufacturers for LEDs used in practice today are about 25000 hours.

2.3.2 Additional quality criteria - colour temperature

The correlated colour temperature (Tc [K]), is the temperature of a Planckian (black body) radiator whose perceived colour most closely resembles to that of a given stimulus of the same brightness and under specified viewing conditions.

The color temperature has nothing to do with the quality of light but very much with the subjective perception and habit. The color temperature indicates the amount of red or blue light. Reddish light is referred to as warm white, blue light as cold white. In between is the so-called neutral white. The color temperature is measured in Kelvin. Especially in the household sector, a warm white light is generally prefered.

- Warm white: 2700 to 3500 Kelvin (2700 K incandescent lamp, halogen lamp 3000 K)

- Neutral white: 3500 to 5000 K

- Cool white: 5000 to 10000 Kelvin (Daylight 6500 K)

The problem is that for the currently offered products a very wide range of color temperature for LEDs is available which is a consequence of the large manufacturing

[7] 'Colour rendering index' (Ra), which is the effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant.

tolerances[8]. There are products available with specific and accurate color temperatures, but at relatively high-cost.

It is currently discussed to define standard values / fixed color temperatures, similarly to FLs (proposed in the LED quality charter[9] and as requirement in the new regulation)

- Bulbs (halogen and incandescent): range between 2500 to 2800 Kelvin
- Fluorescent: fixed color temperatures: 2700, 3000, 4000, 5400, 6500 Kelvin
- LEDs: all versions between 2700 and 10000 Kelvin

2.3.3 Quality in production phase

In the last production phase of a LED, the dividing into different fine-grained quality classes is called "binning". The "binning" has a major influence on the quality of the LED product. It takes place through the measuring of photometric and electrical characteristics of the individual chips. Each bin is different in terms of color temperature, brightness and current flow. For the further processing of LED components to modules, the quality of bins is the main criteria. A bin will be generated through robot-controlled assembly of wafers with the same properties. A LED manufacturer must therefore consider at which price he buys which qualities of bins and at which price he sells the finished product. Moreover, there are not always all qualities of bins available on the market. Generally speaking:

- LEDs with high energy efficiency are more expensive
- LEDs with small manufacturing tolerances are more expensive
- LEDs with low color temperarture (warm light) are more expensive
- LEDs with colder color temperatures are more efficient

2.4 Range of use

Today LED lighting is attractive and economic where its unique advantages can be applied:

- very long life-span
- no heat in the luminous flux

[8] See chapter 2.3.3
[9] The link to this quality charter is mentioned in the bibliography (chapter 7).

- UV-free light
- colour modulation
- dimming with little losses

Applications today include:

- Professional field: operating time > 3000 hours per year, e.g. shop illumination or downlights in a hall (hotel, administration, etc.). Further spotlights in museums, working place table light fixtures, hybrid solutions (e.g. indirect fluorescent lamp, direct LED).
- Domestic field: working place and reading lamps, suspensions for dining table, reflectors (low luminance, no heat radiation, instant start up, brilliant light).
- Street lighting: highly precise illumination of streets and walkways without diffused light.

2.5 Product types

Currently most of the LED lamps for domestic lighting are manufactured as so-called retrofit lamps. Retrofit lamps can be seperated into classical lamps and spot lamps. The classical retrofit LED lamps are bulb-, ball- or candle-shaped and emit their light around the room. They are therefore catagorized as "undirected lighting". The spot retrofit LED lamps are used for the directed illumination of objects or surfaces and are therefore catagorized as “directed lighting”. Within this paper, only the LED lamps for undirected lighting are considered.

Retrofit lamps are shaped like traditional incandescent bulbs. These products have the same sockets as conventional bulbs and can be screwed into existing luminaires. Normally those are the E14 and E27 sockets. Because LED modules claim to live (or will in the future) up to 50000 hours, a replacement lamp may no longer be necessary in the future and could disappear with time. It should be noted however, that the life of a LED also depends on the quality of the power supply. Concerns were expressed that simple power supplies may have a shorter lifetime than the life expectancy of LED modules. Long term studies will show if this is the case.

Due to the retrofit shape, the LED modules have an unfavorable dissipator which has a negative influence on quality and lifetime of the lamp. Currently LED retrofit lamps are available up to 12 watts. With rising efficiency of LED performance in the upcoming 2–3 years, the output power will be approximately doubled. A retrofit LED "bulb" light currently costs about 15 to 70 euro. During long operating times (> 3000 hours per year), LED lamps can be an economical alternative to the incandescent lamp. However, it must also be said that energy saving lamps (CFL) are even more economical.

The following figure shows all possible replacement lamps for the confentional light bulb based on the different sockets:

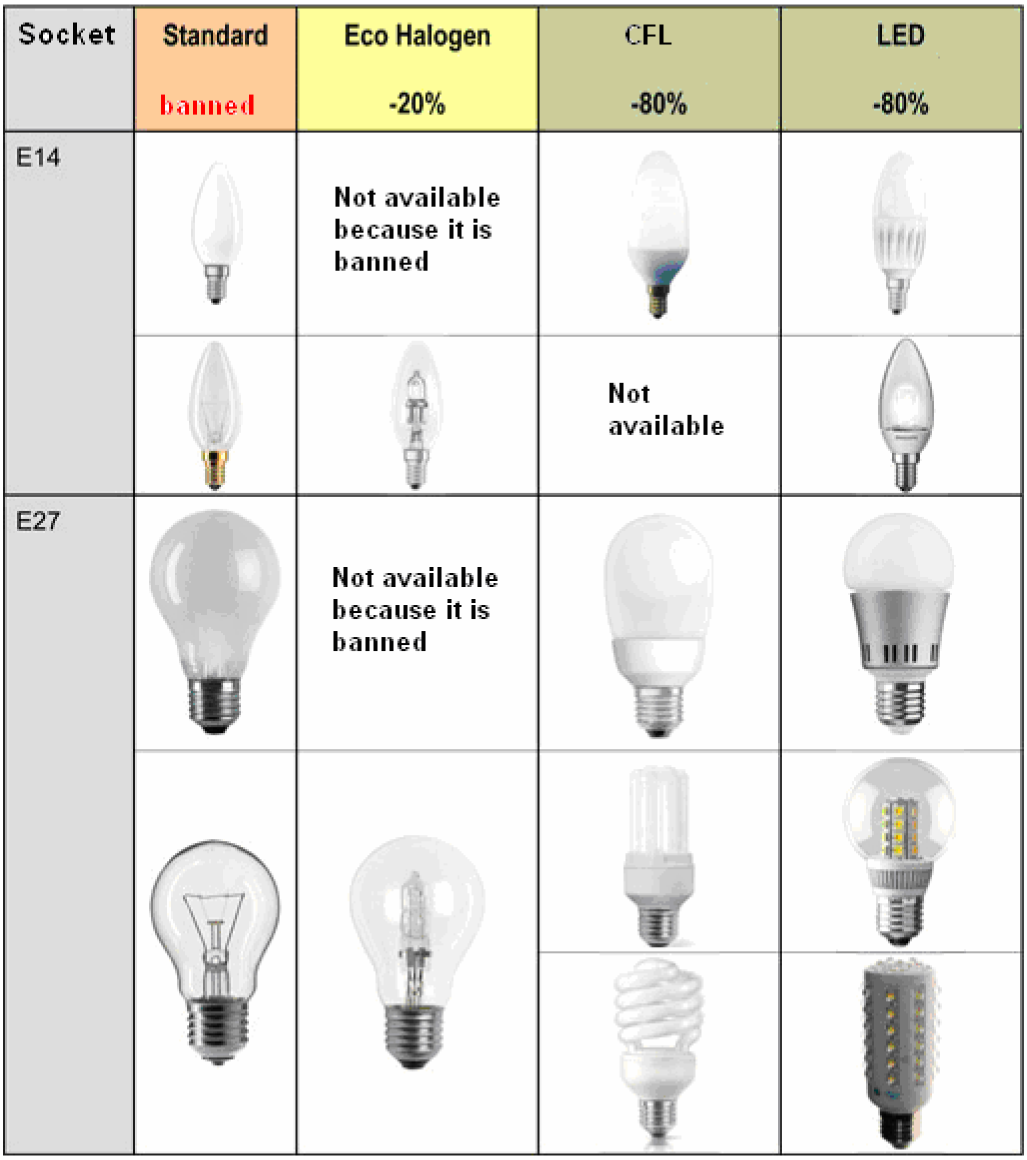

Figure 4 Retrofit replacement lamps[10]

[10] Adapted from: http://www.topten.ch/deutsch/ratgeber/rec_led.html&fromid=

3 Legislations and Standards

The following section gives a short summary on legislation instruments and standards at EU-level which serve as a relevant basis for the information provided in the Euro-Topten initiative.

3.1 The EUP regulation

The EU Ecodesign directive 2005/32/EC will define energy efficency criteria for more than 30 product groups within the next years. These criteria are implemented in specific EU-Regulations. For non-directional domestic lighting the *COMMISSION REGULATION (EC) No 244/2009* has already been published in March 2009.

This regulation sets minimum performance requirements for non-directional household lamps. For LEDs minimum requirements on lamp efficiency, lumen equivalency with incandescent lamps and product information data have been defined. Functionality requirements for LED lamps (like lamp lifetime, switching behaviour, starting time, colour rendering, etc.) have not (yet) been included.

A new EU Ecodesign Regulation “Directional lighting: luminaires, reflector lamps and LEDs” (currently in preparation, outcomes are expected at the end of November 2011) will include the remaining (LED) products: Directional LED lamps, all LED modules and LED control gear. Besides the efficiency and information requirements, also the missing functionality requirements of EU Regulation 244/2009 for LED lamps will be covered here.

3.1.1 Lamp efficacy requirements[11]

For the verification of the lamp efficacy a maximum rated power (Pmax) for a given rated luminous flux (Φ) has to be calculated according to

Table 1. The exceptions to these requirement is shown in Table 2 and the correction factors applicable to the maximum rated power are listed in Table 3.

The calculated maximum rated power is then compared with the rated power of the product. The rated power of the product must not exeed P_{max}.

[11] Source: COMMISSION REGULATION (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps, http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:076:0003:0016:EN:pdf

Table 1: Maximum rated power (Pmax) for a given rated luminous flux (Φ)

Application date	Maximum rated power (P_{max}) for a given rated luminous flux (Φ) (W)	
	Clear lamps	Non-clear lamps
Stages 1 to 5	$0,8 * (0,88\sqrt{\Phi}+0,049\Phi)$	$0,24\sqrt{\Phi}+0,0103\Phi$
Stage 6	$0,6 * (0,88\sqrt{\Phi}+0,049\Phi)$	$0,24\sqrt{\Phi}+0,0103\Phi$

Table 2: Exeptions

Scope of the exception	Maximum rated power (W)
Clear lamps 60 lm ≤ Φ ≤ 950 lm in Stage 1	$P_{max} = 1,1 * (0,88\sqrt{\Phi}+0,049\Phi)$
Clear lamps 60 lm ≤ Φ ≤ 725 lm in Stage 2	$P_{max} = 1,1 * (0,88\sqrt{\Phi}+0,049\Phi)$
Clear lamps 60 lm ≤ Φ ≤ 450 lm in Stage 3	$P_{max} = 1,1 * (0,88\sqrt{\Phi}+0,049\Phi)$
Clear lamps with G9 or R7s cap in Stage 6	$P_{max} = 0,8 * (0,88\sqrt{\Phi}+0,049\Phi)$

The correction factors in Table 3 are cumulative where appropriate and also applicable to the products covered by the exceptions of table 2.

Table 3: Correction factors

Scope of the correction	Maximum rated power (W)
filament lamp requiring external power supply	$P_{max}/1,06$
discharge lamp with cap GX53	$P_{max}/0,75$
non-clear lamp with colour rendering index ≥ 90 and $P \leq 0,5 * (0,88\sqrt{\Phi}+0,049\Phi)$	$P_{max}/0,85$
discharge lamp with colour rendering index ≥ 90 and Tc ≥ 5 000 K	$P_{max}/0,76$
non-clear lamp with second envelope and $P \leq 0,5 * (0,88\sqrt{\Phi}+0,049\Phi)$	$P_{max}/0,95$
LED lamp requiring external power supply	$P_{max}/1,1$

3.1.2 Product information requirements on LEDs

The mandatory product information which has to be provided for consumers on product packaging as well as on websites of manufacturers according to the EU-regulation (No 244/2009) is listed in the following:

Information to be provided on product packaging of non-directional household lamps, any type and therefore for LEDs as well:

- Nominal flux of the lamp (lm)
- Nominal life time of the lamp (hours)
- Number of switching cycles before premature lamp failure

- Colour temperature (in Kelvin)
- Warning if the lamp cannot be dimmed or can be dimmed only on specific dimmers
- If designed for optimal use in non-standard conditions, information on those conditions
- Lamp dimensions in millimeters (length and diameter)
- Claim of equivalence with incandescent lamp has to follow the specifications in the regulation
- Term 'energy saving lamp' or any similar product related promotional statement about lamp efficacy may only be used if the lamp complies with the efficacy requirements applicable to non-clear lamps in Stage 1

Information to be available on free access websites:

- Rated wattage (0,1 W precision)
- Rated luminous flux
- Rated lamp life time
- Lamp power factor
- Lumen maintenance factor at the end of the nominal life
- Starting time (as X,X seconds)
- Colour rendering.

- For lamps containing mercury:
  - o Instructions on disposal in case of accidental lamp breakage;
  - o Recommendations on how to dispose of the lamp at its end of life.

- ***Electromagnetic Compatibility (EMC) Directive 2004/108/EEC***

Though at a very low level, LEDs produce electromagnetic radiation, as any other product connected to the mains. The Council Directive 2004/108/EEC of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive) on the one hand regulates the electromagnetic emissions of lighting equipment in order to ensure that, in its intended use, such equipment does not disturb radio and telecommunication nor other equipment. On the other hand, the Directive also regulates the immunity of such equipment to interference and seeks to ensure that this equipment is not disturbed by radio emissions normally present used as intended.

- ***Directive 2002/95/EC on Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)***

The RoHS Directive stands for "the restriction of the use of certain hazardous substances in electrical and electronic equipment". This Directive bans the placing on the EU market of new electrical and electronic equipment containing lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants. The LEDs are covered by the directive because of the LED platine with its power cords, wires and contact points.

Exemptions from these requirements are for example:

- mercury in compact fluorescent lamps not exceeding 5 mg per lamp
- mercury in straight fluorescent lamps for general purposes not exceeding halo-phosphate 10 mg
- tri-phosphate with normal lifetime 5 mg
- tri-phosphate with long lifetime 8 mg
- mercury in straight fluorescent lamps for special purposes
- mercury in other lamps not specifically mentioned in this annex
- lead in glass of fluorescent tubes.

There are no exemptions for luminaires and ballasts.

- ***Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)***

The WEEE Directive aims at:

- reducing waste arising from electrical and electronic equipment (EEE);
- making producers of EEE responsible for the environmental impact of their products, especially when they become waste.
- encouraging separate collection and subsequent treatment, reuse, recovery, recycling and sound environmental disposal of EEE.
- improving the environmental performance of all those involved during the lifecycle of EEE.

- ***93/465/EEC: Council Decision of 22 July 1993 concerning the modules for the various phases of the conformity assessment procedures and the rules for the affixing and use of the CE conformity marking, which are intended to be used in the technical harmonization directives***

This Decision establishes a range of procedures for assessing the conformity of industrial products to the "essential requirements" laid down by the technical harmonisation Directives. It aims to protect public interests such as the health and safety of product users.

- ***Low Voltage Directive (LVD) 73/23/EEC***

The Low Voltage Directive (LVD) 73/23/EEC seeks to ensure that electrical equipment within certain voltage limits both provides a high level of protection for European citizens and enjoys a Single Market in the European Union. The Directive covers electrical equipment designed for use with a voltage rating of between 50 and 1000 V for alternating current and between 75 and 1500 V for direct current. It should be noted that these voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment.

3.2 Relevant International Test Standards

This chapter shortly lists some relevant 'test standards or guidelines' related to LED lamps. A “test standard or guideline” is defined as a procedure that sets out a test method.

- ***IEC 60061: “Lamp caps and holders together with gauges for the control of interchangeability and safety”***

Contains the recommendations of the IEC regarding lamp caps and holders in general use, together with relevant gauges, with the object of securing international interchangeability.

- ***IEC 62031 (2008-01) Ed. 1.0: “LED modules for general lighting – Safety specifications”***

This International Standard specifies general and safety requirements for LED modules: LED modules without integral control gear for operation under constant voltage, constant current or constant power; self-ballasted LED modules for use on d.c. supplies up to 250 V or a.c. supplies up to 1 000 V at 50 Hz or 60 Hz.

- ***IEC 62471 (2006-07) Ed. 1.0: “Photobiological safety of lamps and lamp systems”***

This standard provides guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. In particular, it specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LEDs but excluding lasers, in the wavelength range from 200 nm through 3000 nm.

- ***IEC 62560 ed1.0: “Self-ballasted LED-lamps for general lighting services by voltage > 50 V – Safety specifications”***

IEC 62560:2011 specifies the safety and interchangeability requirements, together with the test methods and conditions required to show compliance of LED-lamps with integrated means for stable operation (self-ballasted LED-lamps).

- ***IEC/PAS 62612:2009(E): Self-ballasted LED-lamps for general lighting services – Performance requirements***

Specifies the performance requirements for self-ballasted LED lamps with a supply voltage up to 250 V, together with the test methods and conditions required, intended for domestic and similar general lighting purposes, having a rated wattage up to 60 W and a rated voltage of up to 250 V AC or DC.

- ***DIN EN 62663-1 (Draft): "Non-self-ballasted LED lamps – Part 1: Safety requirements (IEC 34A/1399/CD:2010)"***

This draft specifies safety and interchangeability requirements, together with the test methods and conditions, required to show compliance of non-self-ballasted LED lamps, intended for general lighting purposes, having a rated wattage up to 60 W, a rated voltage up to 120 V ripple free d.c.

- ***IES LM-79-2008: "Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Product"***

This approved method describes the procedures and precautions for performing reproducible measurements of total luminous flux, electrical power, luminous intensity distribution and chromaticity of solid-state lighting (SSL) products for illumination purposes under standard conditions.

- ***IES LM-80-08: "Measuring Lumen Maintenance of LED Light Sources"***

This document provides the methods of the measurement of lumen maintenance of sources including LED packages, arrays and modules only. Lumen maintenance is a characteristic measured under controlled conditions. Performance in a particular application may be different.

- ***ANSI Standards on Product Performance, Measurement and Safety***

The American National Standards Institute (ANSI), Washington, D.C., www.ansi.org, oversees the creation, promulgation, and use of thousands of industry norms and guidelines, including the following key standards of relevance to solid-state lighting (SSL) products.

- C78.377, "Specifications for the Chromacity of Solid State Lighting Products," will specify the recommended chromacity ranges for white light LEDs with various correlated color temperatures (CCTs) and ensure communication of chromacities to consumers.

- C82.SSI1, "Power Supply," will specify operational characteristics and electrical safety of SSL power supplies and drivers.

- C82.77-2002, "Harmonic Emission Limits - Related Power Quality Requirements for Lighting," will specify the maximum allowable harmonic emission of SSL power supplies.

- TM-16-05, “IESNA Technical Memorandum on Light-Emitting Diode (LED) Sources and Symptoms,” will provide a general description of LED devices and systems and answer common questions about the use of LEDs.

- RP-16, “Nomenclature and Definitions for Illuminating Engineering Addendum,” will provide industry-standard definitions of lighting terms, including all lighting technologies. The document is currently being updated to include definitions of SSL lighting terms.

- LM-79*, “IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products,” will specify procedures for measuring total luminous flux, electrical power, luminous efficacy, and chromaticity of SSL luminaires and replacement lamp products.

- LM-80*, “IESNA Approved Method for Measuring Lumen Depreciation of LED Light Sources,” will specify procedures for determining lumen depreciation of LEDs and LED modules (but not luminaires) related to effective useful life of the product.

- NFPA 70-2005, “National Electrical Code,” requires that most SSL products must be installed in accordance with the National Electrical Code.

- 47 CFR Part 15, “Radio Frequency Devices,” specifies FCC requirements for maximum allowable unintended radio-frequency emissions from electronic components, including SSL power supplies and electronic drivers.

- 8750, “Outline of Investigation for Light-Emitting Diode (LED) Light Sources for Use in Lighting Products,” will specify the minimum safety requirements for SSL components, including LEDs and LED arrays, power supplies, and control circuitry.

- 1598, “Luminaires,” specifies the minimum safety requirements for luminaires. The requirements in this document may be referenced in other documents such as UL 8750 or separately used as part of the requirements for SSL products.

- 1012, “Power Units Other Than Class 2,” specifies the minimum safety requirements for power supplies other than Class 2 (as defined in NFPA 70-2005).

- 1310, “Class 2 Power Units,” specifies the minimum safety requirements for Class 2 power supplies (as defined in NFPA 70-2005).

- 1574, “Track Lighting Systems,” specifies the minimum safety requirements for track lighting systems.

- 2108, “Low-Voltage Lighting Systems,” specifies the minimum safety requirements for low-voltage lighting systems.

- 60950-1, “Information Technology Equipment - Safety - Part 1: General Requirements,” specifies the minimum safety requirements for electronic hardware.

3.3 IEA - 4E Solid State Lighting Annex

Launched in July 2010, this annex aims to work internationally to support the work that is being done on a national level to address the main challenges with SSL technologies. Everyone needs straighforward, reliable and internationally recognised prodecures to test for basic SSL quality.

Main tasks of the SSL Annex:

- Develop SSL Quality Assurance - work to clarify the SSL market worldwide, reduce the risks in using SSL and provide governments and consumers recommendations that they can trust when investing in SSL products.

- Harmonize SSL Performance Testing - work with global testing labs to increase the quality and confidence of SSL labs' test results, work to assess a range of existing SSL test procedures and build a system of testing that is manageable, robust and acceptable to a broad range of stakeholders.

- Standards and Accreditation - work with existing accreditation bodies to develop a structure for world-wide interim reliability of SSL testing labs' performance data.

More information can be found on http://ssl.iea-4e.org/.

4 Economic and Market Analysis

The technology and the performance of white LEDs are developing very fast. Actually, the availability of specific LED products on the market is very short, as new and more efficient LEDs come on the market every six months. Customers buying LEDs once or twice a year only might find it confusing that products are different every time they visit a shop.

Due to the fact that LED lamps have been available on the market only for a short time and therefore are representing a very small market share, no relevant market data can be found at the moment. Therefore the results of a product test will be presented in the following chapter. This product test of 14 LED retrofit lamps was carried out in October 2010 by the Swiss Federal Office of Metrology (METAS) and the Swiss agency for efficient energy use (SAFE). The results have been published in January 2011 through the Swiss consumer oriented television show “Kassensturz”12.

4.1 Methodology

One product per model was tested, and the most important physical parameters were measured:

- luminous flux,
- wattage and efficiency,
- colour temperature,
- colour rendering (Ra),
- power factor,
- luminous intensity distribution (in comparison to standard bulb).

The product information was checked for completeness and correctness.

4.2 Results

Good results were obtained:

- Most LED retrofit lamps are as efficient or even more efficient than compact fluorescent lamps (about 60 lm/W). The best efficiency measured was 94 lm/W.

[12] Test of 14 LED retrofit lamps in October 2010 – Summary of Test Results (in English).
PDF download at: http://www.topten.eu/uploads/File/Test_LED-lamps_Oct2010.pdf

- All tested lamps have warm white light similar to incandescent lamps (2600 – 3500 Kelvin).
- Some LED retrofit lamps on the market already replace 60 Watt incandescent lamps.
- Replacements for 75 W and even 100 W bulbs are expected to enter the market this year.

High quality is not guaranteed, though:

- 4 of the 14 tested lamps had an unsatisfying colour rendering index (CRI) between 55 and 68. The CRI informs about the quality of the light compared to daylight. It is good (value 80 or higher) for all household lamps with the exception of some LED lamps. The CRI only needs to be declared on the internet, but not at the point of sale. The Ecodesign requirements in discussion set a minimum CRI of 90 for LED retrofit lamps.
- Not all lamps are of high efficiency: the lowest measured value was 34 lm/W.
- With one exception, the light distribution of LED retrofit lamps (red line) differs from incandescent lamps (blue line). More light is emitted downwards and less sidewards or upwards (see figure 5).
- ‘Corn cob’ LED retrofit lamps emit most light to the sides (see figure 5, first image from the right).

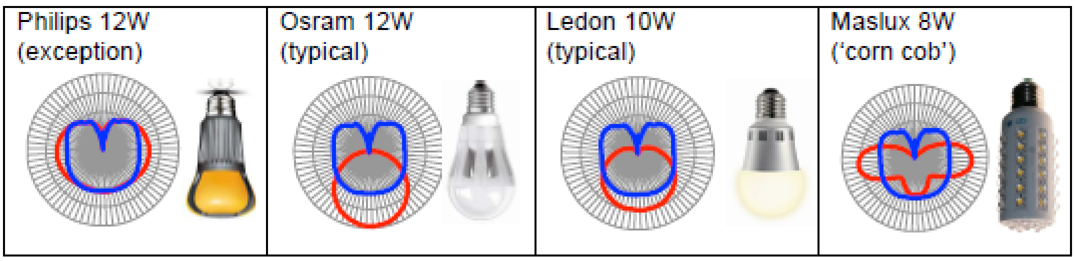

Figure 5 Measurement of LED retrofit lamps13

[13] The diagramm itself shows the Illumination of light against the angle of radiation. The light distribution of LED retrofit lamps are represented through the red line and incandescent lamps through the blue line.

4.3 Cost effectiveness

During long operating times (> 3000 hours per year), LED lamps can be already used as an economical alternative to the incandescent lamp. Under these circumstances, however, energy saving lamps (CFL) are even more economical than LEDs. The following table summarizes the calculation.

lamp type	Classic 40W	ESL 8W	LED 8W
amount of lighting unit	1 exemplar		
power	40 W	8 W	8 W
avarage life time	1 000 h	8 000 h	25 000 h
burning time	3 500 h/a		
electricity costs	0,17 €/kWh		
CO_2 -Faktor	0,5 kg CO2 /kWh		
burning time / year	7 000 h		
amount of lamps / year	8 Lampen	1 Lampe	1 Lampe
purchase costs	26,40 €	10,00 €	39,00 €
energy consumption / year	280 kWh	56 kWh	56 kWh
electricity costs / year	47,60 €	9,52 €	9,52 €
overall costs / year	74,00 €	19,52 €	48,52 €
CO_2 -Emission / year	140 kg CO_2	28 kg CO_2	28 kg CO_2

Figure 6 Economical comparison14

4.4 Manufacturers and Distributors

Some major global manufacturers of LED components are:

- Cree (USA, www.cree.com)
- Lumiled (www.philipslumileds.com)
- Nichia (Japan, www.nichia.co.jp)

[14] Adapted from: Qualitätsmerkmale der LED-Beleuchtung – Aktueller Stand der Technik, Vorteile, Problempunkte und Entwicklungspotential, Bundesamt für Energie BFE, Auftragnehmer: eteam GmbH, Autor: Stefan Gasser, 1.09.2099, page 38.

- Osram (Deutschland, www.osram-os.com)
- Philips (Global, www.philips.com)
- General Electrics (www.gelightingsolutions.com)

The only factory in Europe is placed in Regensburg near Munich belongs to Osram LED. It started in 2008 with 2,000 employees and an annual production of 10 billion LED chips per year.

Driven by government subsidies and soaring demand from new applications such as LCD-TV backlighting and general illumination, China's Light-Emitting Diode (LED) market is set to more than double from 2009 to 2014. The domestic Chinese LED market covers numerous applications, including LED displays, street lighting, general illumination, traffic signals, flash lighting for handset key pads and digital still cameras and the backlighting of large-sized LCD panels in LCD-TVs, laptops and other displays.

5 Selection Criteria

This chapter does not define specific target values to be met by Topten products in all Euro-Topten partner countries. According to the Topten concept, each country has to develop specific Topten lists of its own depending on the products available on the national market. Thus, the specific thresholds for Topten lists depend on the products offered at national level and will be more or less stringent depending on the number of efficient products available.

The intention is rather to provide some recommendations regarding the criteria to be considered in Topten product listings and to give an idea of the efficiency of products currently offered on the market.

5.1 Lamp categorisation

Lamp categorisation for Topten lists should consider the different lamp types offered on the market respectively requested by the consumers. Lamp categorisation for non-directional LED lighting for the convenience of consumers shall distinguish between the following categories:

- Sockets (e.g. E27, E14)
- Shapes (e.g. classic/bulb, candle)
- further subdivision according to watts or lumens (Note: Lumen and watts are not linear for LED lamps)

Examples on current categorization can be found on several Topten-websites already providing information on lighting products (see www.topten.eu). Example from www.topten.eu:

- Classics E27 <300lm
- Classics E27 300-470lm
- Classics E27 >470lm
- Classics E14
- Candles E14

5.2 Lamp information

The following information should be shown on the Topten websites (in the tables) to ensure that the consumer gets sufficient information also on quality criteria other than energy efficiency:

- Wattage (W)
- Luminous efficiency (lm/W)
- Nominal flux of the lamp (lm)
- Nominal life time of the lamp (hours)
- Color rendering index (Ra)
- Color temperature (in Kelvin)
- Power factor
- Lamp base (E14/E27)
- Dimmable (yes/no)
- Lamp dimensions in millimeters (length and diameter)
- Equivalence with incandescent lamp (W)
- Price, electricity costs in 15 years

5.3 Lamp selection criteria

The following section provides some recommendations regarding requirements for Topten lamps. It is not the intention to indicate precise mandatory requirements since real requirements for Topten lists will differ from market to market according to the country. The selection of topten products should be based on the:

- Luminous efficacy: >= 40 lm/W
- Lamp life: minimum 20,000 hours
- Color temperature: between 2600 - 3200 K
- Color rendering index: CRI >= 80

6 Additional Considerations

6.1 Short time goals

The challenge is to retrofit incandescent lamps with LED lamps of good quality – alternatively users will install mainly new halogen lamps with only slightly lower energy consumption. The barriers for this development are current high prices for LED lamps of good quality and the variation in performance of LED sources in the market is far too large. Many customers may have bad experience with use of LED lamps and that will threat consumer confidence in LED lighting performance and savings. This might create a delay in market acceptance and a slowing down of the LED penetration rate. Strong uncertainty is caused by inconsistent declaration and partly missing standardisation. With the ANSI standard, the US is ahead of Europe in this matter although for non-directional domestic lighting the *COMMISSION REGULATION (EC) No 244/2009* has already been published in March 2009. However, for LEDs this regulation only sets minimum requirements on lamp efficiency, lumen equivalency with incandescent lamps and product information requirements. Functionality requirements for LED lamps (like lamp lifetime, switching behaviour, starting time, colour rendering, etc.) have not been included. A new EU Ecodesign Regulation “Directional lighting: luminaires, reflector lamps and LEDs” (currently in preparation) will include the missing functionality requirements and cover the remaining (LED) products like directional LED lamps (spots).

6.2 Pros

- High Quality LEDs have an equal energy efficiency as CFLs. The normal energy efficiency of high quality products is in the range of 50–60 lm/W. The best value measured was 95 lm/W. The energy efficiency of an energy saving lamp is in the range of 60 lm/W. Declaration is often poor: instead of efficiency in real-life usage many producers declare unrealistic lab measurement results; sometimes even fantasy values are declared.

- High Quality LEDs have better light quality than energy saving lamps (CFLs).

- Immediate start (start-up sequence of saving lamps up to 2 minutes)

- Applicable even at low temperatures (in contrast toenergy saving lamps (CFLs))

- Long life time (typical value: 50,000 hours with 70% light output), (depends on heat dissipation; life time of power supply may be shorter

- No ultraviolet or infrared radiation in the light (important for lightening in museums, food and textile)

- Continuous dimming without losses
- Great development potential

6.3 Cons

- In addition to the traditional lamp manufacturers (Osram, Philips and General Electric to produce 75% of world demand for lamps), many new manufacturers are present in the market, e.g. LED Cree Leader (www.cree.com). This leads to very different LED qualities offered in the market. The declaration is often very poor, and the most important criteria, "energy efficiency" and "color rending" are usually not stated.
- Overheating due to improper construction reduces the life of the LED massively.
- Information on LEDs often differ from measured values (equivalent incandescent lamp power, luminous flux and power)
- The power of a single LED is currently between 1 and 5 watts.
- The current market price is high or confusing.

6.4 Health issues

Issues relating to the effects on health and well-being of artificial light are discussed in three recent publications. The links to the full reports can be found in chapter 7.

<u>IES position statement and DOE white paper:</u>

The Illumination Engineering Society (IES) has released a position statement entitled "Effects of Exterior Lighting on Human Health (PS-03-10)," which is not specific to LEDs. The document states that "optical radiation detected by the retina impacts an individual’s behavior, psychology, and perception of the environment. The position of the IES is to promote and encourage a more complete understanding of human responses to optical radiation leading to improved designs for all lighted environments." This has to be achieved through additional research with specific emphasis on additional field research to document typical exposures to optical radiation in exterior settings.

Meanwhile, the DOE Solid-State Lighting program has produced a White Paper entitled "Light at Night: The Latest Science," in July 2010. The white paper concludes that, given the available research, it is unclear what changes, if any, should be made to current best-practice lighting design. "It is clear that additional peer-reviewed research and validation are required to determine the relative significance of the visual and the photo-neural effects of typical light exposures," says the report.

ANSES highlights risks from LED lighting:

ANSES, the French Agency for Food, Environmental and Occupational Health & Safety, has published a report entitled (in English): " Lighting systems using light-emitting diodes: health issues to be considered," which focuses squarely on potential problems caused by LED lighting. The full report is available in French only, but the report summary (in English) says that risks have been identified concerning the use of certain LED lamps, raising potential health concerns for the general population and professionals. "The issues of most concern identified by the Agency concern the eye due to the toxic effect of blue light and the risk of glare," says the report, adding that the blue light necessary to obtain white LEDs causes "toxic stress" to the retina.

Blue light causes a photochemical risk to the eye, says the report, the level of which depends on the accumulated dose of blue light to which the person has been exposed, which is generally the result of low-intensity exposure repeated over long periods. The report says that 3 groups are particularly at risk: children, populations which are already light-sensitive, and workers likely to be exposed to high-intensity lighting.

The other main risk is from glare. The report say that, for indoor lighting, it is generally agreed that luminance higher than 10,000 cd/m² causes visual discomfort whatever the position of the lighting unit in the field of vision. Because the emission surfaces of LEDs are highly-concentrated point sources, the luminance of each individual source can be 1000 times higher than the discomfort level.

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