

Luminaire efficiency: what mandatory and voluntary labels achieve, and what they should achieve in the future

Eva Geilinger, Patrik Janett, Stefan Gasser, Stamatis Sivitos, Francisco Zuloaga, Eric Bush

Topten International Services, HTW Chur, elight GmbH, ECOS, Topten International Services, Topten International Services

Abstract

The European Union (EU) energy label for household luminaires is relatively young; 2014/2015 is the second retail season during which it is available for consumers. This label differs from all other mandatory EU energy labels in that it does not refer to the product's annual energy consumption or energy efficiency. Instead it indicates only the energy efficiency class of light sources (lamps) included in the luminaire and available alternatives. Existing ecodesign regulations require only information about the LED module alone to be provided with luminaires. This is misleading because light is lost in diffusers and shades, and components for power conversion and lighting control use extra energy.

This paper discusses measurement results for about 200 luminaires evaluated by the voluntary Topten label during the last two years. Since 2009 the energy efficiency project „Topten“ has collaborated with Switzerland's two largest retailers, Coop and Migros, as well as other suppliers and manufacturers in labelling the best household luminaires in shops and catalogues. Light output, power and colour spectrum are measured for the label.

The measurement results show that there are large saving potentials in household luminaires which are currently not communicated to consumers. Luminaire efficiency ranges from 10 - 100 lumens per watt; and standby energy consumption is common and sometimes unnecessarily high. Measured colour rendering values of LED luminaires were generally good though could improve.

The paper concludes with recommendations for retailers and policy makers on how to provide better consumer information on household luminaires. Specific improvement options for the EU energy label and ecodesign requirements for luminaires are identified.

Introduction

The EU energy label provides key information about energy consumption and efficiency performance of many energy using products. Despite a new label, the luminaires we buy for our homes use more energy than stated on the packaging. Seldom there is information on standby power. 0.5 watt in off-mode (standby-mode) annually consumes 4 kWh; for a 10 watts LED luminaire, this adds 40% to energy costs¹. Another cause of misleading information is that power is declared for the LED module alone; power of components for power conversion and lighting control (e.g. drivers, touch-sensors, etc.) are usually omitted. These typically add another 1-2 watts to the luminaire's total power. Even more misleading are declared lumens (luminous flux). They too are given for the LED module alone. Typically 5-70% of the light is lost inside the luminaires' shades and diffusers. A luminaire that is declared at 550 lumens (approx. equivalent to a 45 watt incandescent bulb) might really only deliver 300 lumens (see examples in Table 1). Consumers might chose an unsatisfying luminaire when LED lamps are built-in and cannot be replaced.

This paper will briefly outline the EU energy label and the voluntary Topten label for luminaires; it will discuss measurement results for about 200 tested luminaires; and then make recommendations for better consumer information on household luminaires (both for EU policy and retailers).

¹ 1 year = 8760 hours. 10 watts during 1000 hours/year + 0.5 watt during 7760 hours/year = 10 kWh (use-mode) + 4 kWh (standby-mode) annually.

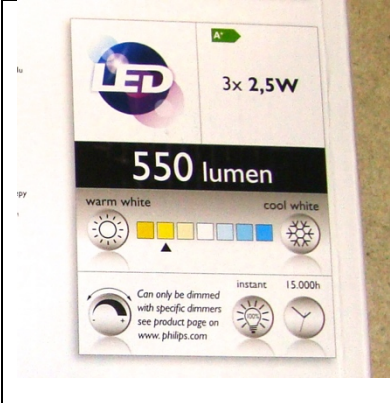

			
On packaging: 3 x 2.5 W 550 lumens	Measured: 8.5 W (+13%) 299 lumens (-46%)	On packaging: 31.2 W ca. 3700 lumens	Measured: 31.0 W (-1%) 2463 lumens (-33%)

Table 1: Typical examples of luminaire packaging and differences to actual watts and lumens

EU energy label

The EU energy label for household luminaires, EU regulation No 874/2012 [1], is relatively young. It has been in use during two retail seasons (winter 2013/2014 and winter 2014/2015). This label differs from all other mandatory EU energy labels since it does not refer to the product's energy consumption, light output or energy efficiency. Instead it indicates only the energy efficiency class of light sources (lamps) included in the luminaire and available alternatives. There are numerous designs for the label reflecting the variety of light sources. Figure 1 shows a selection of them.

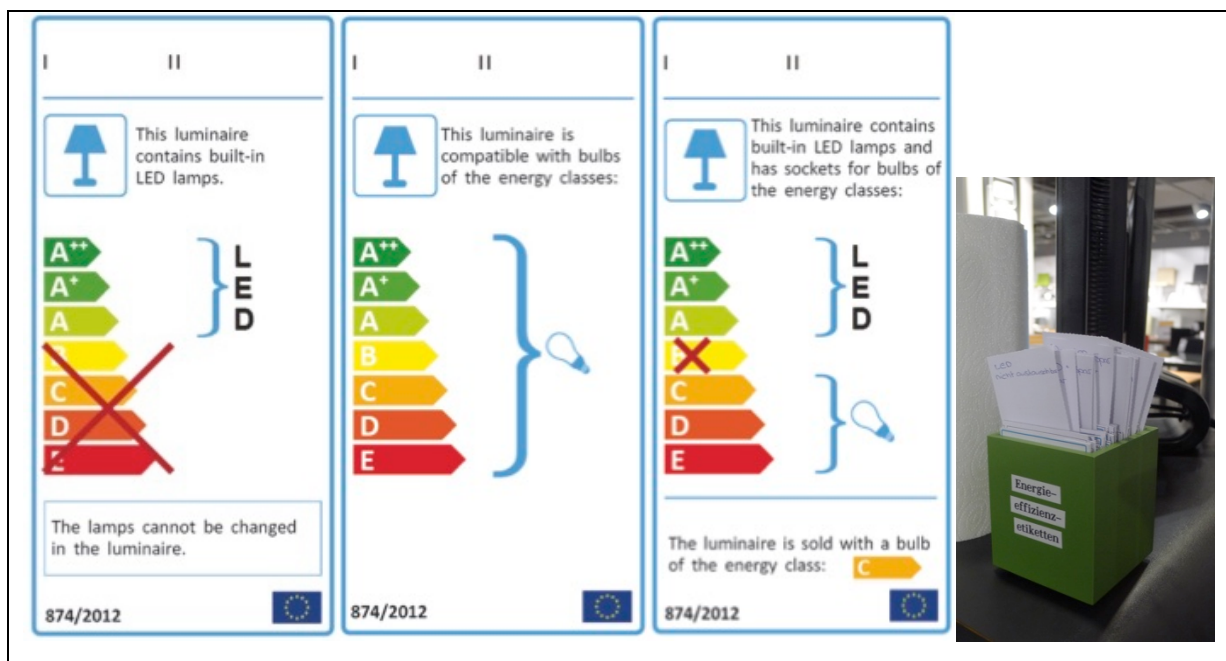


Figure 1: EU energy label for household luminaires according to EU regulation No 874/2012 [1] (selection of possible designs). On the right: box with labels in a luminaire shop.

You will see later in this paper that we propose to apply the EU energy label for lamps also to luminaires with built-in LEDs. Unlike the luminaire label, the label for lamps comprises an actual rating of the product's energy efficiency. The calculation of the energy efficiency index is shown in Figure 2. Several choices for power correction and useful luminous flux make the calculation rather complicated.

For the calculation of the energy efficiency index (EEI) of a model, its power corrected for any control gear losses is compared with its reference power. The reference power is obtained from the useful luminous flux, which is the total flux for non-directional lamps, and the flux in a 90° or 120° cone for directional lamps.

The EEI is calculated as follows and rounded to two decimal places:

$$EEI = P_{cor}/P_{ref}$$

where:

P_{cor} is the rated power (P_{rated}) for models without external control gear and the rated power (P_{rated}) corrected in accordance with Table 2 for models with external control gear. The rated power of the lamps is measured at their nominal input voltage.

Table 2

Power correction if the model requires external control gear

Scope of the correction	Power corrected for control gear losses (P_{cor})
Lamps operating on external halogen lamp control gear	$P_{rated} \times 1,06$
Lamps operating on external LED lamp control gear	$P_{rated} \times 1,10$
Fluorescent lamps of 16 mm diameter (T5 lamps) and 4-pin single capped fluorescent lamps operating on external fluorescent lamp control gear	$P_{rated} \times 1,10$
Other lamps operating on external fluorescent lamp control gear	$P_{rated} \times \frac{0,24\sqrt{\Phi_{use}} + 0,0103\Phi_{use}}{0,15\sqrt{\Phi_{use}} + 0,0097\Phi_{use}}$
Lamps operating on external high-intensity discharge lamp control gear	$P_{rated} \times 1,10$
Lamps operating on external low pressure sodium lamp control gear	$P_{rated} \times 1,15$

P_{ref} is the reference power obtained from the useful luminous flux of the model (Φ_{use}) by the following formulae:

For models with $\Phi_{use} < 1\,300$ lumen: $P_{ref} = 0,88\sqrt{\Phi_{use}} + 0,049\Phi_{use}$

For models with $\Phi_{use} \geq 1\,300$ lumen: $P_{ref} = 0,07341\Phi_{use}$

The useful luminous flux (Φ_{use}) is defined in accordance with Table 3.

Table 3 Definition of the useful luminous flux	
Model	Useful luminous flux (Φ_{use})
Non-directional lamps	Total rated luminous flux (Φ)
Directional lamps with a beam angle $\geq 90^\circ$ other than filament lamps and carrying a textual or graphical warning on their packaging that they are not suitable for accent lighting	Rated luminous flux in a 120° cone (Φ_{120°)
Other directional lamps	Rated luminous flux in a 90° cone (Φ_{90°)

Figure 2: Calculation of the energy efficiency index for lamps according to EU regulation No 874/2012, Annex VII [1]

Topten label

Since 2009 suppliers and manufacturers have collaborated with the energy efficiency project „Topten“ to label the best household luminaires (Figure 3). Among them are Switzerland's two largest retailers, Coop and Migros. The luminaires are tested for energy efficiency, standby power, light colour (also called colour temperature) and colour rendering. Only products that meet Topten's ambitious criteria (Table 2) are then labeled as energy-saving, eco-friendly articles in the shop. They are also published on the Topten website (Figure 4).



Figure 3: The Topten logo showcases the most energy efficient household luminaires in shops

Luminaire efficiency factor	≥ 50 lumens per watt except when $>90\%$ indirect lighting ≥ 55 lumens per watt
Standby power	≤ 0.5 W except when luminaires have an in-built dimmer ≤ 1.0 W
Colour rendering index (CRI)	≥ 80 (only for luminaires using LED)
Colour temperature	≤ 6500 kelvins (only for luminaires using LED)

Table 2: Criteria for energy efficient household luminaires defined by Topten [4]

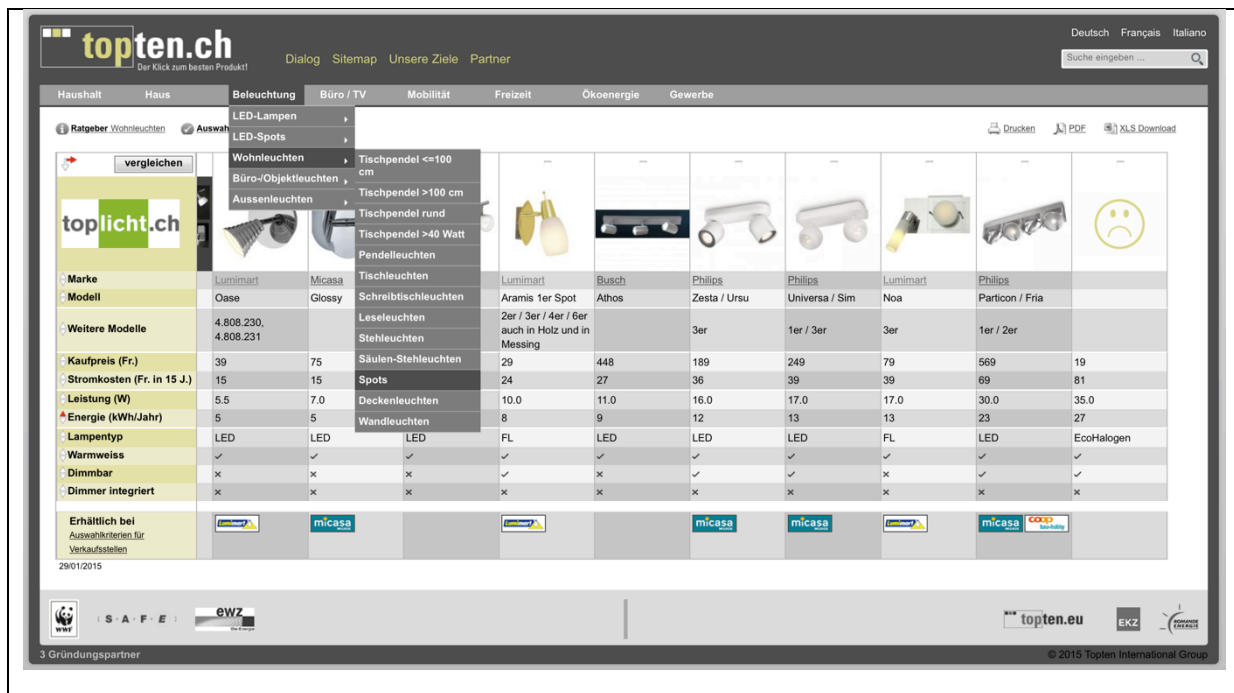


Figure 4: The Topten website publishes the lists of the most energy efficient household luminaires

Measurement results for 193 household luminaires

This chapter presents and discusses measurement results from the last two years, submitted for the voluntary Topten label for household luminaires. Testing was done at the Swiss Alpine Laboratories for Testing of Energy Efficiency (S.A.L.T.) in Chur, Switzerland [5]. Retailers and manufacturers chose for testing a total of 193 luminaires expected to be highly energy efficient (since they should meet the Topten criteria and be accordingly labelled in the shops). Therefore the dataset consists of mostly LEDs (158 built-in, 6 retrofit GU10) and some luminaires with compact or linear fluorescent lamps (29). Luminaires with incandescent or halogen lamps were not evaluated because they cannot meet the Topten energy efficiency criteria. The majority of luminaires are “directional” (here we call them “directional” when $>90\%$ of the light output is within a cone with angle of 180° ²). However “directional” does not mean that they are all meant for accent lighting. In fact, most of them are designed for general lighting. It is typical that light output of LED luminaires is distributed in a semi-sphere instead of a whole sphere like we are used to from incandescent, halogen or fluorescent lighting. See light distribution categories used by Topten in Table 3 and luminaire types in the data set shown in Figure 5.

² This includes slightly more luminaires than the definition of directional lamps in EU regulation No 874/2012 (energy labelling of lamps) which states: ‘Directional lamp’ means a lamp having at least 80% light output within a solid angle of π sr (corresponding to a cone with angle of 120°).

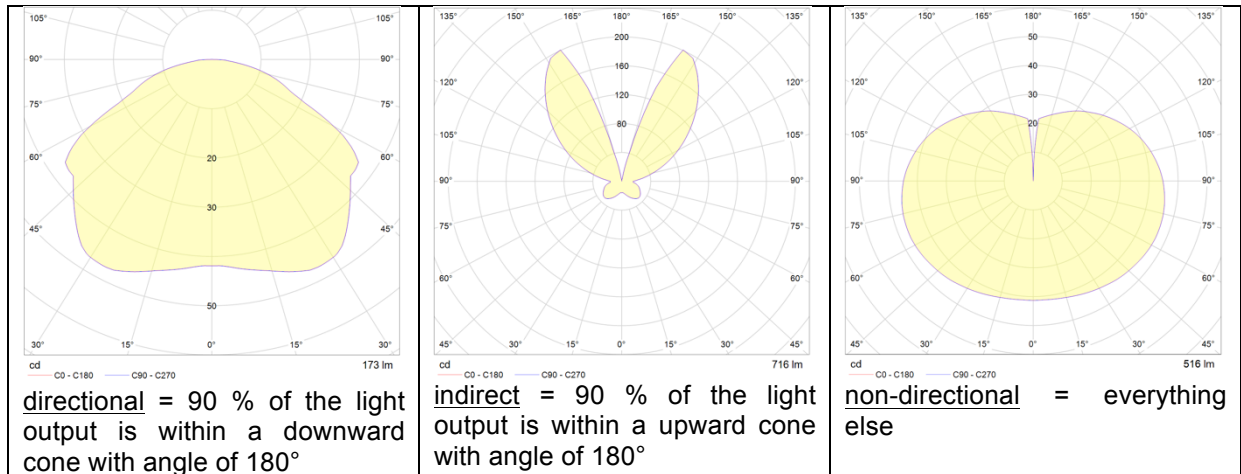


Table 3: Light distribution categories used by Tipten

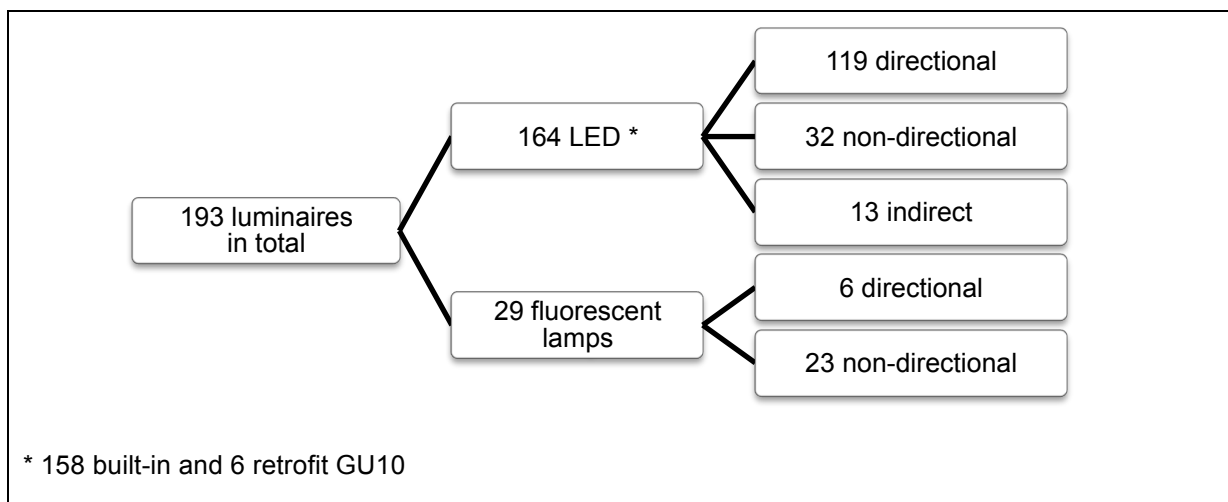


Figure 5: Overview of luminaire types in the data set

Test methodology and results

The luminaires were tested in a climatized room with stabilised electrical power supply. Equipment and tested parameters:

- Power meter (Voltech Poweranalyzer PM1200): power in use-mode (watts), power in standby-mode (watts), power factor (-)
- Spectroradiometer (Specbos 1201): colour temperature (kelvins), colour rendering (-), colour spectrum (image file)
- Photogoniometer (engineered by HTW Chur, lux meter Minolta T10): total luminous flux (lumens), light distribution curve (image file and .ldt file)

Power and luminous flux, colour temperature

The 193 household luminaires are characterised by power generally no higher than 40 watts and lumens no higher than 2600 lumens (see Figure 6). As expected most LED luminaires are warm white while only 12 are neutral white (popular for bathrooms for example) and (again) 12 are daylight white (popular for desk lighting for example):

- warm white = colour temperature <3500 kelvins
- neutral white = colour temperature 3500-5000 kelvins
- daylight white = colour temperature >5000 kelvins

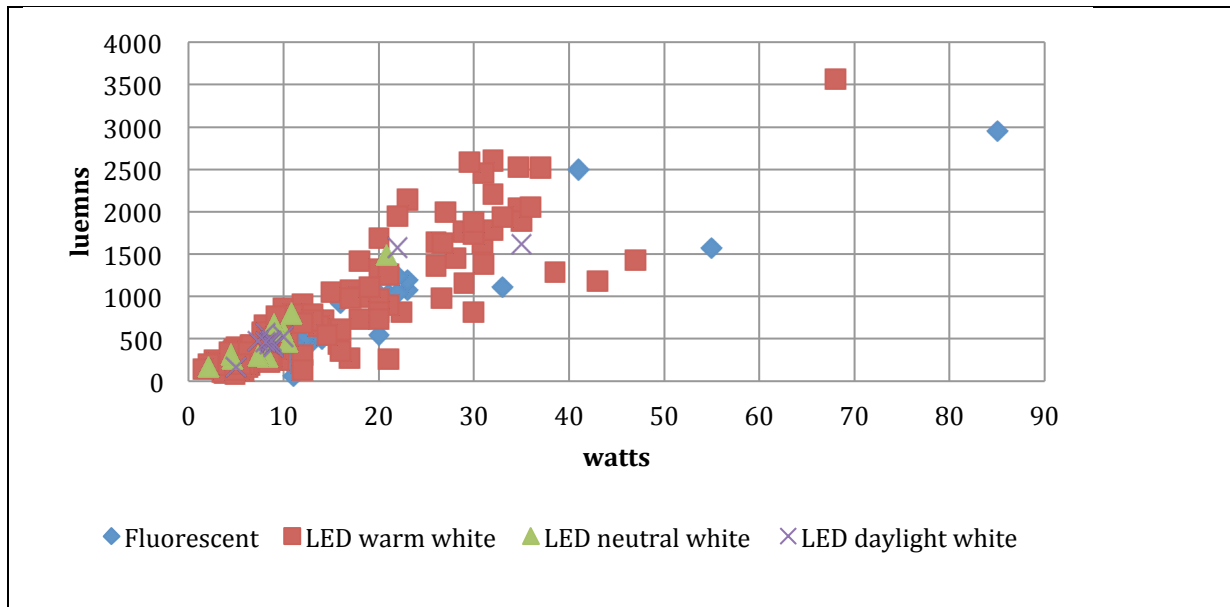


Figure 6: Measured watts and lumens for the 193 tested luminaires

Declared lumens on packaging compared to measured lumens

For the 131 LED luminaires for which there was a lumens value declared on the packaging, the declared and measured values were compared. Figure 7 shows that declared lumens are in many cases substantially higher than measured lumens.

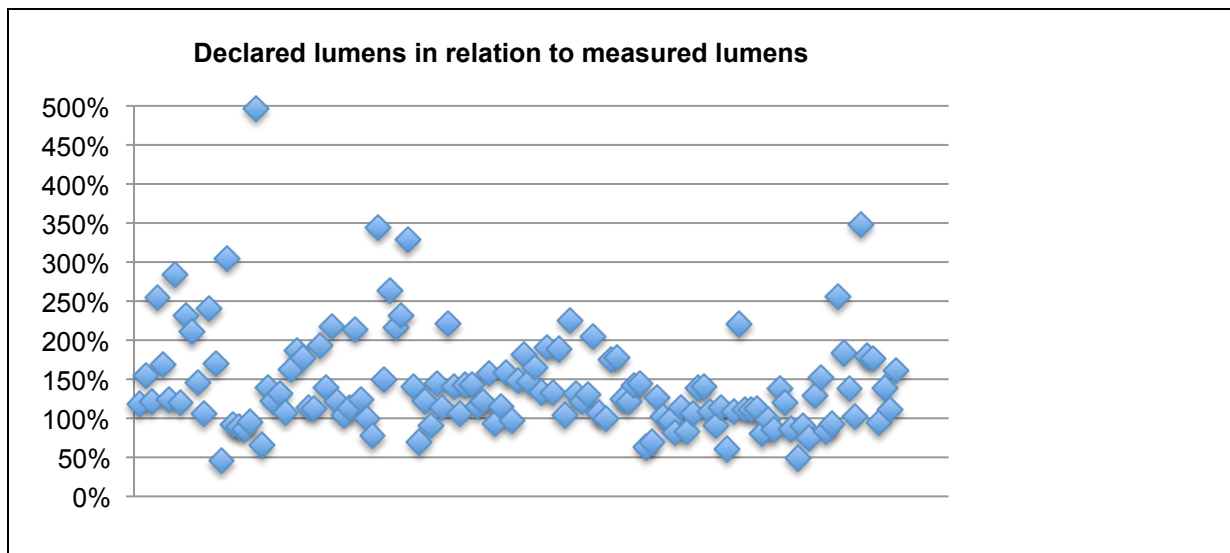


Figure 7: Lumens declared on packaging compared to measured lumens (100% = measured) for 131 LED luminaires (no declaration available for rest)

Luminaire efficiency factor (lumens per watt)

Luminaire efficiency is expressed by the ratio of total luminous flux in lumens and total power in watts. This ratio is also called luminaire efficiency factor (LEF). Measured efficiency ranges from 10 – 100 lumens per watt. The best result for luminaires using LED is 96 lm/W, and for luminaires with fluorescent lamps it is 61 lm/W (Figure 8).

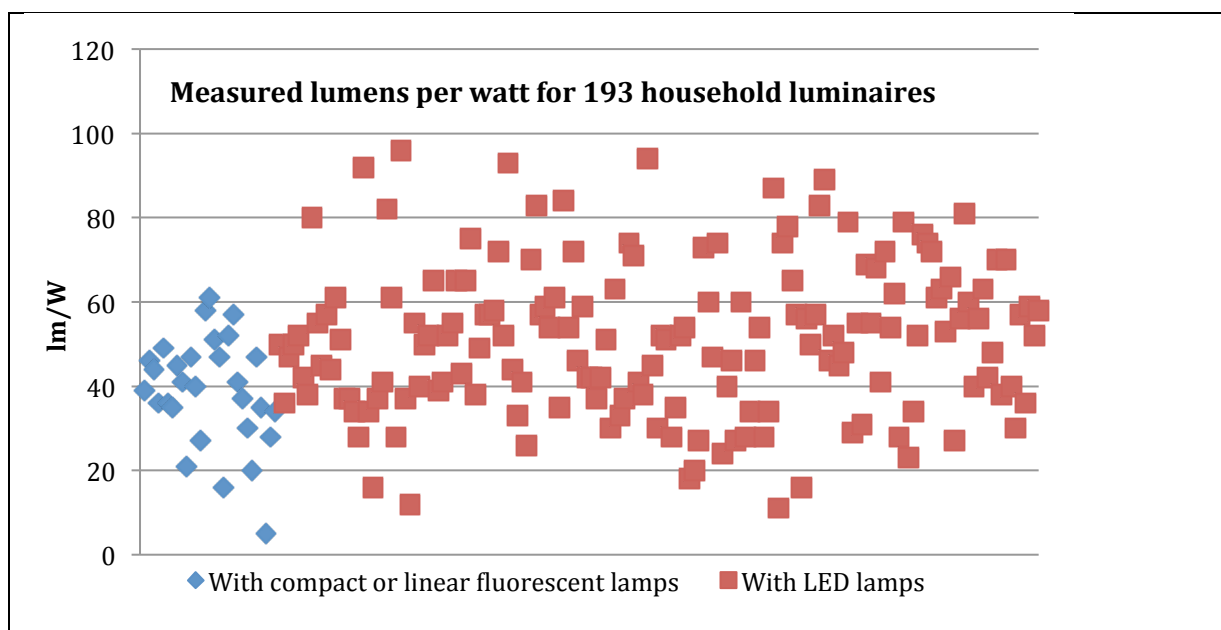


Figure 8: Measured lumens per watt for 193 household luminaires

Applying energy efficiency classes to LED luminaires

For the 158 luminaires with built-in LEDs, the energy efficiency class was calculated as if they were lamps (Annex VI and Annex VII in EU regulation No 874/2012 [1], see also Figure 2). This revealed that 21 luminaires would be in class B and 2 in class C (Figure 9). The EU energy label fails to show this; instead it presents the notion that all luminaires with built-in LEDs are in classes A, A+ or A++ (Figure 1). The savings are large and consumers would certainly benefit from being aware of these. A luminaire in class A++ saves:

- over 80% compared to class B or C
- over 50% compared to class A
- over 25% compared to class A+

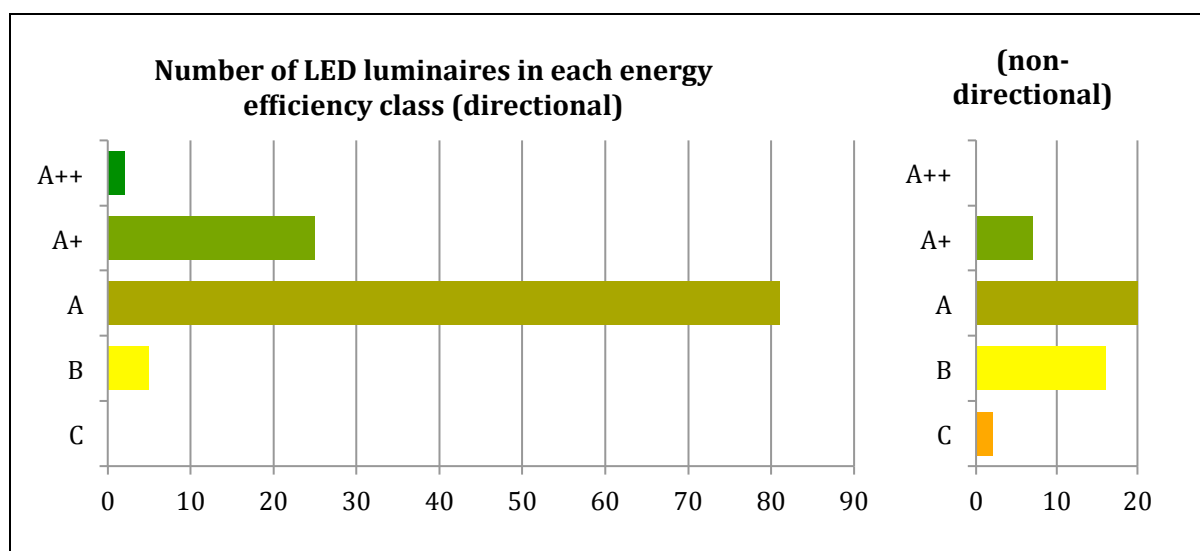


Figure 9: Number of LED luminaires in each energy efficiency class

Standby

Every third tested luminaire consumes energy in off mode. Measured standby power tends to be around 0.5 watts (Figure 10). A few tested products consume more than 1 watt in off mode, and maximum standby power was measured at 3.6 watts. Standby energy use is very common among

floor-standing, table and desk luminaires (57 of 77 tested products). Wall or ceiling mounted luminaires seldomly consume standby energy (6 of 116 tested products); when they do, it is typically because additional light switches, dimmers etc. are built into the luminaire.

In the EU, standby consumption is partially limited through requirements for control gear and ballasts in regulations No 1194/2012 [2] and No 245/2009 [3]. The limits are 0.5 watts for fluorescent lamps' ballasts (without integrated ballast) and 1.0 watt for other power converters like halogen converters and transformers and LED drivers (0.5 watt as from 1 September 2016). A summary of the respective requirements is given in Table 4: Energy efficiency requirements for lamp control gear and ballasts.

Other luminaire components can add to standby energy consumption. Typically they are components for lighting control like timer switches, occupancy sensors, light sensors and daylight regulation devices or illuminated switches. All these are not covered by EU requirements. In addition, phase cut dimmers are also exempt from the requirements; this means that practically all dimmers are exempt. Leading edge phase cut dimmers are commonly used with conventional power converters for halogen and incandescent lamps; trailing edge phase cut dimmers are used with electronic power converters for fluorescent or LED lighting.

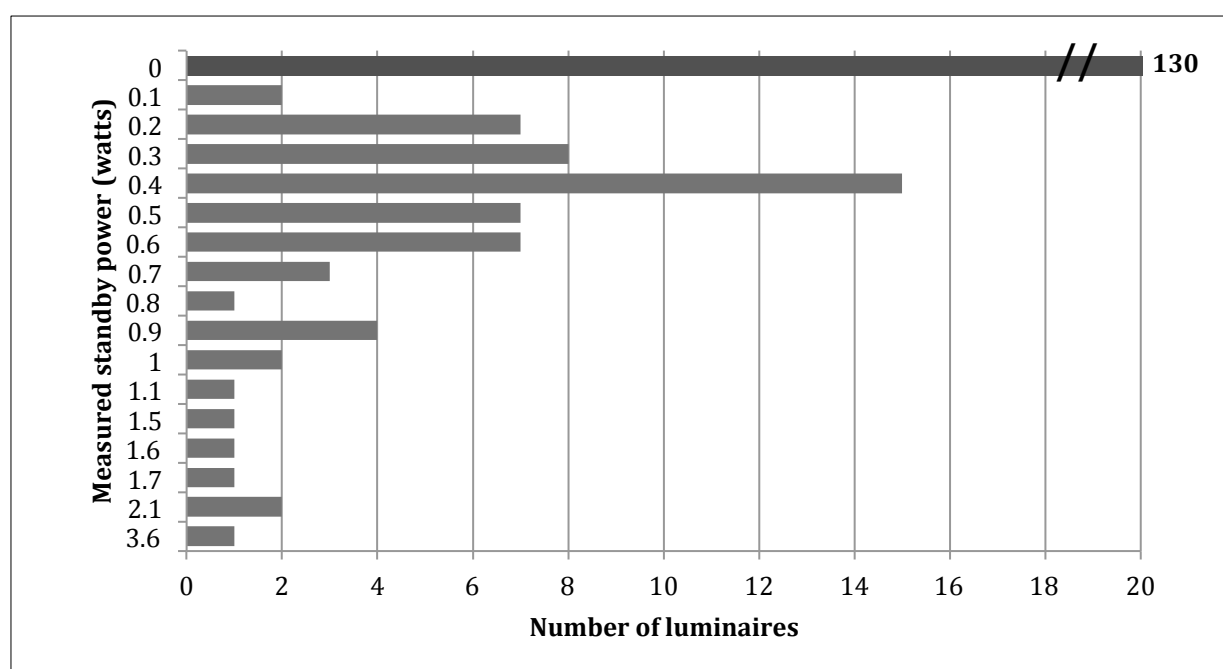


Figure 10: Measured standby power in watts

Colour rendering

The colour rendering index (CRI) is a measure of how colours appear in artificial light compared to daylight. The best value is 100³ and typically reached by halogen lamps. Values between 77 and 86 are accepted as good and typically reached by fluorescent and LED lamps. To enter the EU market LED lamps must have a CRI value of at least 80 (EU regulation No 1194/2012 [2]). LED lamps can reach excellent CRI values of nearly 100, however there is a trade-off with luminous efficiency. With the astonishing technological development of luminous efficiency in the last years (LED lamps reaching over 100 lumens per watt), demand for LED lamps with excellent CRI could increase in the coming years.

Most of the 164 measured LED luminaires showed a good CRI of 80 or higher (Figure 11). Still 1 in 5 had a lower CRI (32 products). In many cases this is likely due to lamp shades and diffusers that can reduce colour rendering quality; however in some cases where the LEDs are barely covered we suspect that there are also bad LEDs with lower CRI than allowed.

³ Note that CRI is not a value in percent. There can be negativ values as well.

The CRI value is an average calculated for 8 pastel colours. To only consider pastel colours is arguably not the best evaluation of colour rendering. There are 7 additional sample colours that would ideally be considered as well. They are saturated colours, leaf green and two skin colours. The saturated red, and to a lesser degree the saturated blue, rarely appear natural in fluorescent or LED light. See Figure 12 with all 15 sample colours and examples of typical CRI values for fluorescent and LED lamps.

The 164 measured LED luminaires were screened for exceptionally good colour rendering. Excellence in colour rendering was defined as:

- Ra (average of 8 pastel colours) must be ≥ 87 and
- each of the 7 additional colours must be ≥ 50 .

Based on these criteria, 12 of 164 products (less than 10%) could be identified to have excellent colour rendering. Figure 12 shows examples of the detailed CRI values for different luminaire types.

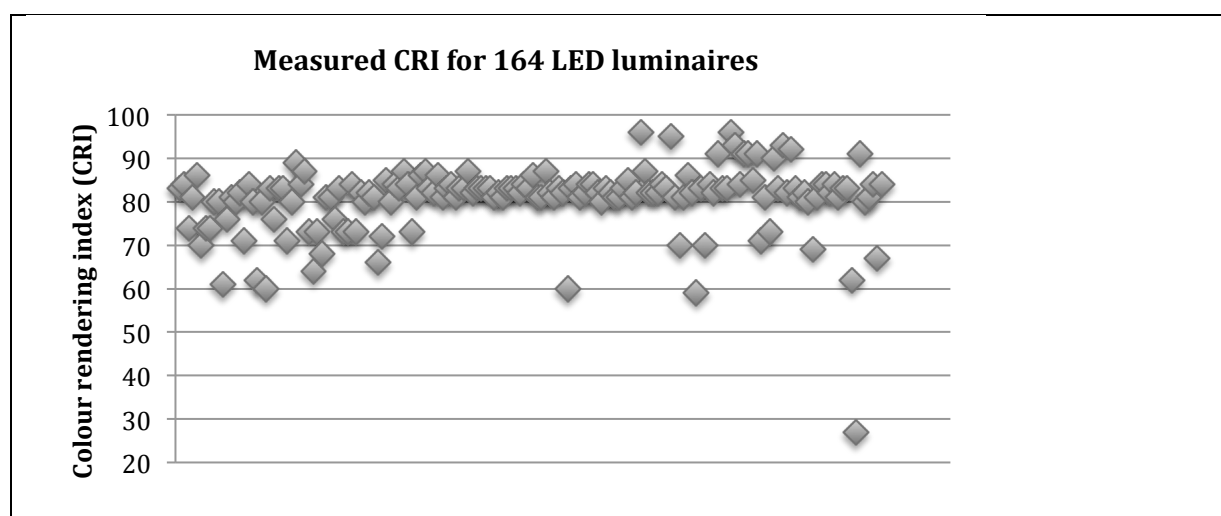


Figure 11: Measured colour rendering index (CRI) for 164 LED luminaires

<div> <div> CRI color samples </div> <div> <div>R1= 98.4</div> <div>R2= 95.2</div> <div>R3= 52.9</div> <div>R4= 87.8</div> <div>R5= 86.8</div> <div>R6= 83.1</div> <div>R7= 86.6</div> <div>R8= 63.1</div> <div>R9= -6.2</div> <div>R10= 52.2</div> <div>R11= 78.0</div> <div>R12= 44.3</div> <div>R13= 95.0</div> <div>R14= 67.0</div> </div> <div> <div>JIS color sample</div> <div>R15= 90.9</div> <div> Ra (mean value of R1 - R8) 81.74 </div> </div> </div>		Typical luminaire with fluorescent lamp
<div> <div> CRI color samples </div> <div> <div>R1= 77.7</div> <div>R2= 87.6</div> <div>R3= 96.2</div> <div>R4= 77.8</div> <div>R5= 77.1</div> <div>R6= 83.4</div> <div>R7= 84.6</div> <div>R8= 59.3</div> <div>R9= 4.7</div> <div>R10= 71.1</div> <div>R11= 74.6</div> <div>R12= 63.0</div> <div>R13= 79.6</div> <div>R14= 97.7</div> </div> <div> <div>JIS color sample</div> <div>R15= 71.0</div> <div> Ra (mean value of R1 - R8) 80.46 </div> </div> </div>		Typical LED luminaire

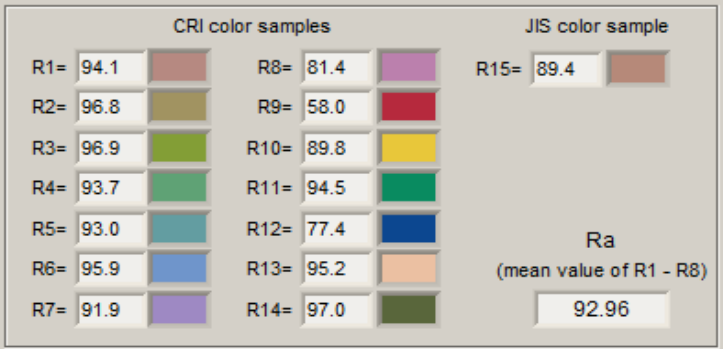
		LED luminaire with excellent colour rendering
---	--	---

Figure 12: Colour rendering index (CRI) values for typical examples of different luminaires

Regulation (EC) No 245/2009 [3]

Since 2012: The power consumption of **ballasts** used with fluorescent lamps without integrated ballast shall not exceed 0,5 W when operated lamps do not emit any light in normal operating conditions. This requirement shall apply to ballasts when other possible connected components (network connections, sensors etc.) are disconnected.

Regulation (EU) No 1194/2012 [2]

As from stage 2 (1 September 2014), the no-load power of a **lamp control gear** intended for use between the mains and the switch for turning the lamp load on/off shall not exceed 1,0 W. As from stage 3, the limit shall be 0,50 W. For lamp control gear with output power (P) over 250 W, the no-load power limits shall be multiplied by P/250 W.

As from stage 3 (1 September 2016), the standby power of a **lamp control gear** shall not exceed 0,50 W.

'lamp control gear' means a device located between the electrical supply and one or more lamps, which provides a functionality related to the operation of the lamp(s), such as transforming the supply voltage, limiting the current of the lamp(s) to the required value, providing starting voltage and preheating current, preventing cold starting, correcting the power factor or reducing radio interference.

(Ballasts, halogen convertors and transformers and Light Emitting Diode (LED) drivers are examples of light source control gears.)

Exempt are 'control devices':

'control device' means an electronic or mechanical device controlling or monitoring the luminous flux of the lamp by other means than power conversion, such as timer switches, occupancy sensors, light sensors and daylight regulation devices. In addition, phase cut dimmers shall also be considered as control devices;

Table 4: Energy efficiency requirements for lamp control gear and ballasts

Conclusions and recommendations for provision of better information to consumers

For EU policy

The luminaire tests discussed in this paper show that there are large saving potentials in household luminaires, but they are currently not communicated to consumers. Even within LED luminaires, which might be assumed to be energy efficient generally, the luminaire efficiency factor ranges from 10 - 100 lumens per watt; thus LED does not automatically mean "energy efficient". The EU energy label should make these saving potentials visible.

In the mid-term, we therefore recommend to update the existing EU energy label for household luminaires with a real rating of luminaire efficiency (based on measured luminaire data and the calculation of an energy efficiency index). Currently it is the only existing label that does not give any information on energy consumption or energy efficiency of the product it concerns.

In the short-term, we propose the inclusion of luminaires with built-in LEDs into the scope of EU regulations No 1194/2012 (ecodesign of directional lamps and LED lamps) and No 874/2012 (labelling of lamps and luminaires) at the next possible opportunity (e.g. the ongoing review of these regulations in 2015), so they will be treated in the same way as LED lamps. Information as well as minimum requirements for luminaire standby power should be added for all luminaires (maximum 0.5 watts for luminaires in total, including integrated dimmers, touch-switches, sensors etc.).

The market share of luminaires with built-in LED lamps is growing. Since these lamps cannot be changed it is important that consumers have the best possible product information. Actual luminous flux, total power, annual energy consumption (including standby-mode) and colour rendering are key pieces of information that are currently not available to consumers. In addition, life time and number of switching cycles until early failure are crucial information to choose durable products that can satisfy over many years. All these pieces of information would be provided to consumers with the above described amendments of EU regulations No 1194/2012 and No 874/2012. Additional benefit for consumers could be generated if annual energy consumption was declared for all luminaires (for example based on 1000 hours in use-mode and 7760 hours in standby-mode).

Standby energy consumption is common in household luminaires. The test results show that 1 in 3 luminaires consumes energy in standby-mode. We also noted that standby energy consumption is not part of mandatory product information and is not communicated to consumers, even though it substantially increases annual energy consumption of the product. Minimum requirements only partially cover standby energy consumption via the requirements for control gear and ballasts, but not standby energy consumption of dimmers, illuminated switches etc. This is insufficient since there are currently luminaires with up to 3.6 watts standby power, which is unnecessarily high.

For retailers

The test results show that colour rendering of LED luminaires is generally good and in some cases excellent. However, retailers are advised to double-check the colour rendering index (CRI) of all LED luminaires in their assortment (good portable radiospectrometers are available starting at 2000 Euros), since the tests also show that some products might have CRI values that do not comply with EU legislation. Also total power and standby power can easily be measured by retailers who wish to provide better consumer information. Quality power meters are around 300 Euros, and even some new power meters for only 30 Euros can perform precise measurements as well, though those must be tested to verify good performance⁴.

References

- [1] Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires
- [2] Commission Regulation (EU) No 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment
- [3] Commission Regulation (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council

⁴ Examples of power meters that have been tested with verified good performance: <http://www.topten.ch/?page=messgerate>

- [4] Topten Criteria for Household Luminaires,
German: http://www.topten.ch/?page=auswahlkriterien_wohnleuchten&fromid=
French: <http://www.topten.ch/?page=Crit-f-luminaires-d-interieur&fromid=>
Italian: <http://www.topten.ch/?page=Crit-lampade-casa&fromid=>
- [5] S.A.L.T., Swiss Alpine Laboratories for Testing of Energy Efficiency, <http://www.salt-chur.ch>