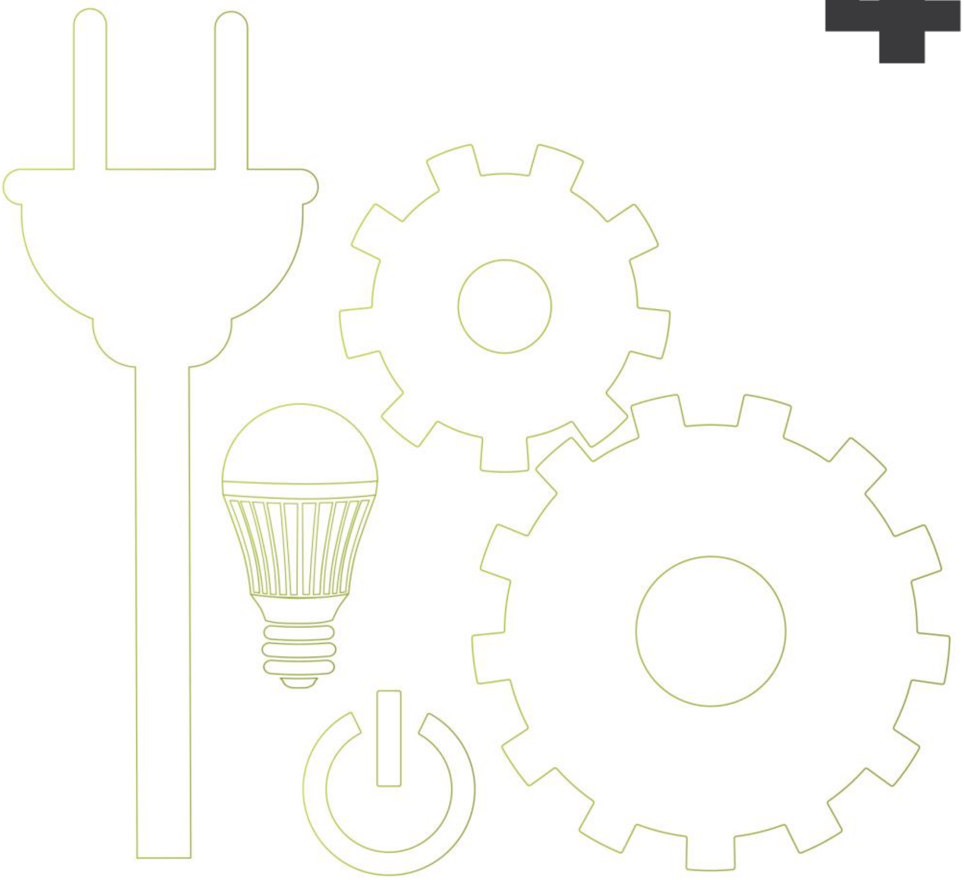

Solid State Lighting Annex: Task 7: Smart Lighting – New Features Impacting Energy Consumption

First Status Report

Energy Efficient End-Use Equipment (4E)
International Energy Agency

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IEA 4E Solid State Lighting Annex
Task 7: Smart Lighting – New Features Impacting Energy Consumption
First Status Report

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About the IEA 4E Solid State Lighting Annex

The SSL Annex was established in 2010 under the framework of the International Energy Agency's Energy Efficient End-use Equipment (4E) Implementing Agreement to provide advice to its member countries seeking to implement quality assurance programmes for SSL lighting. This international collaboration was established by the governments of Australia, Denmark, France, Japan, The Netherlands, the Republic of Korea, Sweden, United Kingdom and the United States of America. China works as an expert member of the 4E SSL Annex. Further information on the 4E SSL Annex is available from: http://ssl.iea-4e.org/

About the IEA Implementing Agreement on Energy Efficient End-Use Equipment (4E)

4E is an International Energy Agency (IEA) Implementing Agreement established in 2008 to support governments to formulate effective policies that increase production and trade in efficient electrical end-use equipment. Globally, electrical equipment is one of the largest and most rapidly expanding areas of energy consumption which poses considerable challenges in terms of economic development, environmental protection and energy security. As the international trade in appliances grows, many of the reputable multilateral organisations have highlighted the role of international cooperation and the exchange of information on energy efficiency as crucial in providing cost-effective solutions to climate change. Twelve countries have joined together to form 4E as a forum to cooperate on a mixture of technical and policy issues focused on increasing the efficiency of electrical equipment. But 4E is more than a forum for sharing information – it initiates projects designed to meet the policy needs of participants. Participants find that pooling of resources is not only an efficient use of available funds, but results in outcomes which are far more comprehensive and authoritative. The main collaborative research and development activities under 4E include:

- The Electric Motor Systems Annex (EMSA)
- The Mapping and Benchmarking Annex
- The Solid State Lighting Annex (SSL)
- The Electronic Devices and Networks Annex (EDNA)

Current members of 4E are: Australia, Austria, Canada, Denmark, France, Japan, Korea, The Netherlands, Switzerland, Sweden, UK and USA. Further information on the 4E Implementing Agreement is available from: www.iea-4e.org

Executive Summary

Smart LED (Light Emitting Diode) lamps, or more commonly simply "smart lamps", are appearing more and more in today's lighting market. These lamps provide an opportunity for the consumer to benefit from smart services, better product quality and energy savings. The focus of this report is to assess the 'smartness' of these lamps in terms of the energy impact utilising the 'smart' functions.

Smart lamps combine technology breakthroughs in wireless communications and LEDs. There are four different categories of smart lamps identified: 1) Domestic user-focused features - wireless colour tuning, dimming, integrated audio speaker, etc., 2) Data delivery - connectivity enabling lamps e.g., with activation of services and/or security monitoring, 3) Professional features – e.g. maintaining a constant flux over life time, and 4) Economising lamps - including sensors and controls in order to optimise and save energy.

Currently, smart lamps fall exclusively into one of the above four categories; however in the future, it's expected that smart lamps may include a mix of features from the four categories. In this report, the focus and measurements are on the first category of lamps but a lot of the analysis also covers smart lamps including data delivery features.

Wireless lamp features (e.g., colour tuning, dimming, gradually changing between lighting scenes over time, connectivity, etc.) implies that smart lamps consume energy whenever mains power is switched on, even when they are not providing lighting but waiting (i.e., monitoring in standby) for an instruction from a control device, like a smartphone or remote control unit. And, smart lamp systems often also require a separate energy consuming gateway device for translating the communication signal between the control device and the lamps.

The first indicative measurements from Australia, Europe and USA show that the standby functions can drastically increase the lamp's total energy use, and depending on the daily hours of operation, the standby energy consumption can even be larger than the energy used for providing lighting. In the future, households potentially may have dozens of wirelessly controlled smart lamps installed, which together could contribute to very high standby energy consumption.

Therefore, the IEA 4E SSL Annex launched a study on the energy performance of smart wireless lighting. Examination of the lamps as well as the communication protocols and gateways provides an evidence base for making policy recommendations to governments.

Indicative measurements collected from laboratories in the countries participating in the SSL Annex show a very large variation in the standby power consumption from 0.15 to 2.70 W. This finding indicates that design improvements in smart lamps are possible.

For smart lamps providing between 200 and 1000 lumens of light, the standby energy consumption represents on average 51 % of the consumption when the lamps are used one hour per day and 35 % when the lamps are used two hours per day. This range of average daily operating hours is typical of the domestic sector in the IEA 4E SSL Annex member countries.

For smart lamps providing between 200 and 1000 lumens of light, the efficacy[1] varied from 34 to 87 lm/W (average 64 lm/W). However, when the lamp is used one hour per day, the *overall efficacy*[2] varied from 9 to 51 lm/W (average 30 lm/W) where a few smart lamps had an overall efficacy below that of incandescent lamps. When the number of operation hours is increased to two hours per day, the overall efficacy varied from 16 to 64 lm/W (average 40 lm/W). This is still low compared to non-smart LED lamps due to the additional electronics associated with the 'smartness' and the necessary standby mode power consumption when they are off.

In addition to the standby consumption in the smart lamps, many systems also use a wireless gateway to facilitate communication with smart lamps in a given space. This gateway, which adds additional energy consumption, can typically accommodate up to 50 smart lamps. If the consumers use different brands of lamps, more than one gateway may be required.

Manufacturers are adding more and more services and features to smart lighting systems, and sometimes it may be worth considering whether that service or feature could be provided in a more energy efficient and/or better quality way using another device or system.

In the future, there may be dozens of wirelessly controlled smart lamps in every home, which taken together could result in very high standby power consumption. The IEA 4E SSL Annex is working to raise awareness of standby energy consumption, and has issued a press release (http://ssl.iea-4e.org/news/smart-lighting) and given a number of presentations at conferences, seminars and workshops on this topic [ref. 3, 4, 5, 6 and 7]. In raising awareness on this important topic, manufacturers will be encouraged to make design improvements that lower the standby power consumption associated with smart lighting.

The SSL Annex is also concerned about the lack of interoperability between different manufacturers' lighting products, which could represent a barrier for large scale use of smart lighting particularly in residential situations. The products being developed, including smart lamps, gateways, luminaires, controls, meters and management systems (software) tend to rely on proprietary hardware and software. In the home, smart lamp communication is performed by a number of wireless protocols. However, even where communication uses the same protocol for different products, the user may still have to use different software applications (apps) to control each product. This lack of interoperability may result in the user being restricted to purchasing all products from a single manufacturer in order to ensure compatibility and easy management. With the evolution of technology, features and software over time, even users relying on one manufacturer may have to make a decision to either start over or live with an existing, increasingly unsuitable or outdated smart lighting system.

Other standards/protocols are used in building automation systems for commercial buildings. Efforts to bring more standardisation and interoperability to the market are underway within manufacturers' alliances and international standardisation organisations, but most are organised around each communication protocol.

[1] Efficacy is the ratio of light output (lumens) of a lamp over the power input (watts), reported in "lumens per watt" (lm/W).
[2] In this report, the term "overall efficacy" makes reference to a 24-hour (or longer period) effective efficacy, taking into account the energy consumed in ON-mode and STANDBY-mode. See definition in the section "Key terms used in the report".

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Acronyms and Abbreviations

4E	Energy Efficient End-use Equipment
ANSI	American National Standards Institute
CCT	Correlated Colour Temperature
CIE	Commission Internationale de l'Éclairage (International Commission on Illumination)
CRI	Colour Rendering Index
DTU	Danmarks Tekniske Universitet (The Technical University of Denmark)
Duv	Chromatic distance to planckian locus
EDNA	Electronic Devices and Networks Annex
ECEEE	European Council for an Energy Efficient Economy
EMSA	Electric Motor Systems Annex
GLS	General Lighting Service (a non-directional incandescent lamp)
IEA	International Energy Agency
IEC	International Electrotechnical Commission
LED	Light Emitting Diode
lm	lumen
RGB	Red Green Blue (referring to colour mixing LED-lamps)
SSL	Solid State Lighting
UK	United Kingdom
USA	United States of America
W	Watts

1 Introduction

LED products offer a number of opportunities to bring new, smart features to the lighting market, enhancing the user-experience and improving quality and service. In general, the smart lighting products market breaks down into four categories of service:

- **Domestic**: The first group offers smart lamp features[3] that are domestic user-focused, such as wireless colour tuning and dimming, programmed sessions where brightness and colours change over time and integrated audio speaker. Typically, a smartphone app is used to control the lamps with network access and communication between the lamps by wireless network interface such as Wi-Fi, Bluetooth, Zigbee, and 6LoWPAN.
- **Data Delivery**: A second group of smart lamps are connectivity enabling lamps distributed throughout a premise to provide extended wireless range, security data, data of consumer movements around a shop possibly with activation of location specific consumer services, etc. Monitoring and adjustment of such systems is possible from anywhere in the world.
- **Professional**: A third group of smart lamps and luminaires is aimed more at the professional market providing features such as prolonging the life through active thermal control or regulation of the drive current and maintaining constant flux output over time.
- **Economising**: A fourth group of smart lamps and luminaires includes sensors and other controls in order to optimise the operation, energy and economy savings. This group includes smart street lighting that dims down when there is no traffic.

Figure 1. Smart lamp examples from the domestic services category

[3] In this report this category only includes smart lamps, but smart luminaires are about to appear in the market.

Currently, smart lamps fall exclusively into one of the above four categories; however in the future, it's expected that smart lamps may include a mix of features from the four categories.

In order to better understand smart lighting features and the energy use associated with these features, the IEA 4E SSL Annex has launched this study on the energy performance of smart lighting including lamps, communication protocols and gateways. The study is expected to provide an evidence base for making policy recommendations to governments.

The IEA 4E SSL cooperates and is coordinating its work with the IEA 4E EDNA. The paragraphs below provide a description of the work conducted by the two annexes:

- The IEA 4E Solid State Lighting (SSL) Annex includes Task 7 "New features impacting LED energy consumption". This task studies smart lamps through laboratory measurements of standby power and how the new smart features such as colour tunability and dimming affect a product's energy consumption (both active and standby consumption), efficacy and the lighting quality (luminous flux, colour temperature, colour rendering, Duv etc.). More information about the 4E SSL Annex work on Smart Lamps can be found at: http://ssl.iea-4e.org/product-performance/new-product-features
- The IEA 4E Electronic Devices and Networks Annex (EDNA) focuses on all different types of network-connected devices, some of which are lighting products. EDNA is working to collect indicative non-laboratory approximate measurements of a wide range of network-connected products including smart lamps. The work is being carried out by semi-technical people in home, office and retail environments. EDNA aims to ensure that such devices use electricity as efficiently as possible and will help align government policies in this area. More Information on the IEA 4E EDNA and its programme of work can be found at: http://edna.iea-4e.org/

This IEA 4E SSL Annex report focuses on domestic smart lighting (the first category listed above) with identification and measurement of energy consumption (such as standby power) associated with the new features incorporated into smart SSL products.

At present, there are no definitions of any efficiency based metrics that adequately capture both the potential functionality and standby modes of smart lamps weighted by the number of hours in the two modes. There is also no international or regional test methodology against which to measure these metrics and smart features as part of a possible regulation. The US Department of Energy (DOE) has just finalised a test procedure for LED lamps [ref. 14] which references IEC 62301 for the standby mode test method, but this procedure does not include a calculation of the overall efficacy. Energy Star also has a test method for measuring standby mode consumption.

This report provides initial guidance on a draft laboratory testing of smart lamps recommended for use as efficiency based metric until a recognised test method or standard is published.

2 Key Terms Used in the Report

The primary focus of this report is the domestic sector including use of smart lamps with wireless features such as colour tuning, dimming, lighting scenes, programmed lighting scenes where brightness plus colours change over time, streaming of music played by a speaker embedded with the product, etc.

2.1 Definition of Key Terms

Below is defined the key terms used in this report.

Table 1. Definitions of key terms

Subject	Key Term	Definition
Smartness	Smart lamp	A lamp that can be controlled via a wireless signal using a smart-phone, remote control unit or other device. Some smart lamp products are part of a dedicated home automation system including many appliances and an integrated energy management system.
	Four categories of smart products	1. Domestic – smart lamps offering domestic user-focused services such as dimming, colour tunability, mood setting and integrated speaker for streaming music; 2. Data Delivery – connectivity enabling lamps distributed throughout a premise to provide extended wireless range, security data, consumers movements around a shop; 3. Professional – smart lamps and luminaires for the professional market offering features such as prolonging life, thermal control and constant flux; 4. Economising – smart lamps and luminaires that incorporate energy saving features including sensors and controls. Actual smart lamps typically fall into one of the above four categories. In the future, smart lamps might include a mix of features from the four categories – some lamps already do that.
Communication	User interface	The communication device through which a user controls smart lamps, typically via an app on a smart phone or a remote control.
	User link	Wireless communication network between the user interface and the gateway, e.g. using protocols such as WiFi or Bluetooth.
	Gateway	A device facilitating communication between the user interface and all the smart lamps as well as between the smart lamps. A gateway is typically housed in a separate enclosure supplied by mains power, but it can also be contained within one of the lamps. In situations where the lamp communicates by use of the general wireless communication, e.g. Bluetooth (provided by smart-phones) or WiFi (provided by a router), there will not be a separate gateway.
	Lamp link	Wireless communications network used as an interface to the lamps and between the lamps. Some lamps use the same network as for the user link with the protocols WiFi or Bluetooth while other lamps use a gateway to in order to shift to use of protocols with lower bandwidth and lower energy consumption such as Zigbee, Z-wave or 6LoWPAN.

Subject	Key Term	Definition
	Protocol	A wireless network communication protocol facilitates the transmission of data between components of a smart lighting system. Definitions and information about the communication protocols WiFi, LiFi, Bluetooth, Zigbee, Z-wave and 6LoWPAN are included in part 2.3 and 2.4 of this report.
Power consumption	ON	Mode where the lamp is producing light in a default state without any dimming. The energy consumption for this mode is defined by the power consumption for the rated luminous flux. Furthermore, the magnitude of the flux and the power consumption are dependent on the selected CCT and this parameter is typically not specified for the rated values by the manufacturer. For some lamps this mode might also include fully integrated extra services as music from the lamp where these extra services may be difficult or impossible to switch off.
	STANDBY	Mode where the lamp is connected to a mains power source and at least one smart network function is activated. For lighting, STANDBY mode occurs when the lamp is turned OFF by the user interface or dimmed to zero visible light but the lamp continues to use energy in order to be ready to receive the next wireless communication from the user interface. Testing has established that for lamps where the light can be switched off by an OFF button or dimmed to zero, the STANDBY power is the same.
Efficacy	Overall Efficacy	The light output per unit power taking into consideration both the energy consumed in ON plus in STANDBY. The overall time period has to minimally be per day, but the accuracy improves with longer periods such as a week or a full year. $$Overall\ Efficacy = \frac{Luminous\ flux\ x\ Time_{ON}}{Power_{ON}\ x\ Time_{ON} + Power_{STANDBY}\ x\ Time_{STANDBY}}$$
	Relative Overall Efficacy	When the Overall Efficacy is divided by the efficacy for the ON mode, the Relative Overall Efficacy is calculated as shown below: $$Relative\ Overall\ Efficacy = \frac{Overall\ Efficacy}{Efficacy_{ON}}$$ $$= \frac{Time_{ON}}{Time_{ON} + \left(\frac{Power_{STANDBY}}{Power_{ON}} \times (24 - Time_{ON})\right)}$$ In case the power consumption is known for the ON mode and the STANDBY mode, this formula can be used to calculate the Overall Efficacy for any duration of ON time. Page 7 provides an example on how to do this calculation.

2.2 Overall efficacy

Figure 2 gives an example of how the overall efficacy varies for a 10 W smart lamp providing 700 lm when the standby power is set to 1 W, 2 W or 3 W and the ON hours are varied between 1 and 24 hours. This example shows:

- With an ON time of 1 hour/day, the overall efficacy is at the level of an incandescent lamp for 2 W and 3 W standby power and halogen lamps for 1 W standby power;
- With an ON time of 2 hours/day, the overall efficacy is at the level of a halogen lamp for 3 W standby power, and rises to approximately twice that of a halogen lamp for 1 W standby power;
- With an ON time below 7 hours/day, the overall efficacy of these smart lamps with standby power 2 W or 3 W are all below the efficacy of a CFL while the similar limit is below 4 hours/day for standby power 1 W;
- The ON period has to be greater than 11 hours/day (for 1 W standby power) increasing to 17 hours/day (for 3 W standby power) before the overall efficacy rises above that of a CFL.
- When the ON time is 24 hours/day, the overall efficacy is naturally equal to the ON efficacy of 70 lm/W.

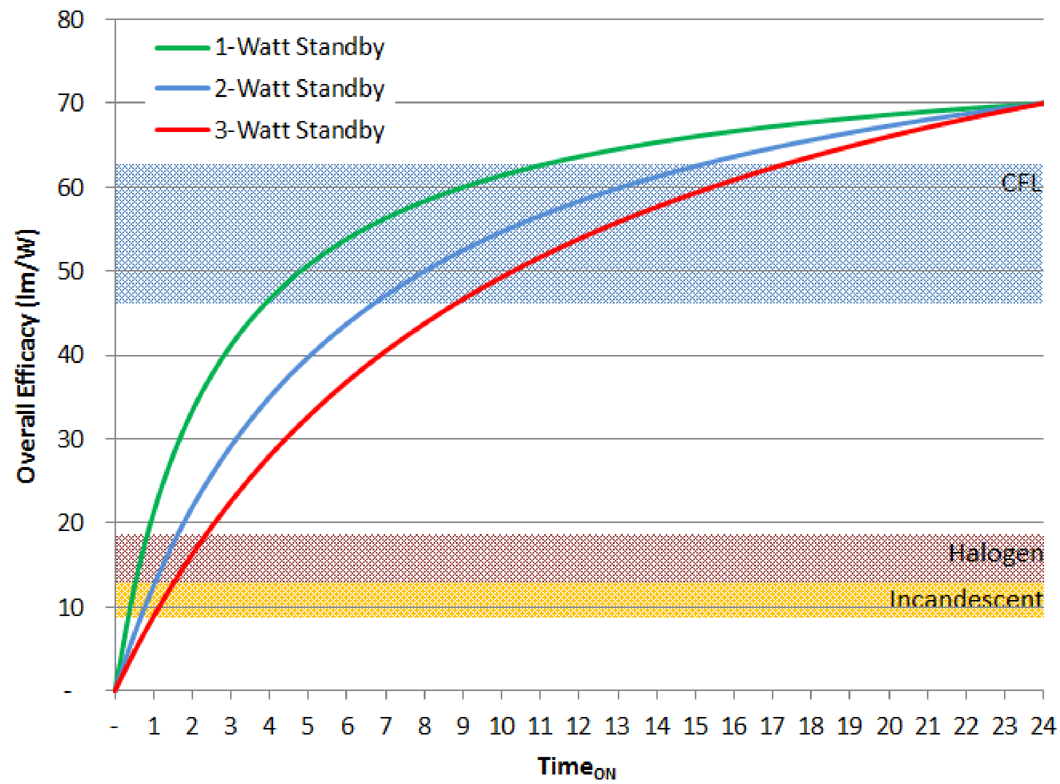


Figure 2. Example of variation in overall efficacy of three 10 W smart lamps providing 700 lm with different standby powers (1, 2 or 3 W) for all hours of ON usage per day

Figure 3 shows the Relative Overall Efficacy when $P_{STANDBY}/P_{ON}$ respectively is 5, 10, 15, 20 and 25 % which covers the standby power range reported from the 27 models tested which provide 200–1000 lumens.

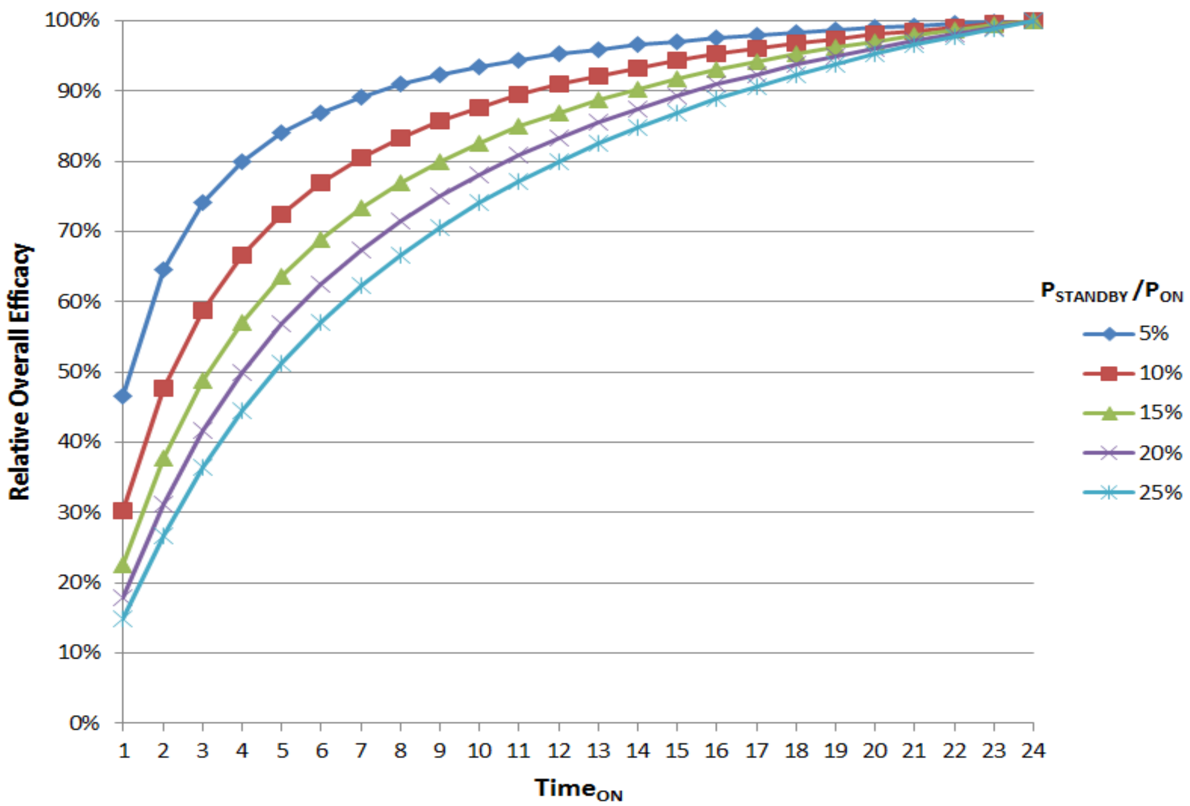


Figure 3. Relative overall efficacy for $P_{STANDBY}/P_{ON}$ being 5, 10, 15, 20 or 25 %

Figure 3 can be used to calculate the overall efficacy in any situation when $P_{STANDBY}/P_{ON}$ is 25 % or less. The procedure is:

- Measure $P_{STANDBY}$ and P_{ON}.
- Calculate $P_{STANDBY}/P_{ON}$.
- Find the relative overall efficacy in Figure 3 based on the two values $P_{STANDBY}/P_{ON}$ and the hours per day when ON.
- Multiply with the efficacy when ON.

Example: If $P_{STANDBY}/P_{ON}$ = 10 % and the lamp is ON for 1 hour/day, then in Figure 3 the curve reveals the relative overall efficacy as 30 %. Thus with an efficacy when ON of 70 lm/W, (similar to the example lamp used in Figure 2) the overall efficacy of the lamp is effectively 21 lm/W (30 % of 70 lm/W), which is in agreement with Figure 2.

2.3 Communication Protocols

This section of the report provides an overview of the most common wireless network communication protocols used with smart lighting.

Section 2.4 describes the application of communication protocols in network architectures.

2.3.1 WiFi

WiFi communication uses radio waves to provide high-speed Internet and network communications between devices. WiFi is a trademarked term that refers to the Institute for Electrical and Electronic Engineers standard, IEEE 802.11x.

The characteristics for WiFi are:

- Star network protocol
- High data rate
- Long distance operating range
- High power consumption (compared to the last three protocols in this section)

2.3.2 LiFi

LiFi communication uses high-frequency LED light modulation (flickering) - at a speed that the human eye can’t detect - to provide high-speed network communication.

The characteristics for LiFi are:

- Star network protocol
- Very high data rate
- Long distance operating range
- High power consumption (compared to the last three protocols in this section)

LiFi is not used in any of the smart lamps purchased and tested in Annex Member Country lighting laboratories.

Many within the lighting industry consider LiFi as a “game changer” because it is a unique feature of LED lamps and the very high data rate (approximately 10 Gb/s). LiFi is expected to be a pivotal technology in future development of data delivery by connectivity enabling smart lamps distributed throughout a premise to provide extended wireless range, security data, data of consumer movements around a shop/museum/building, activation of location specific consumer services, etc. Monitoring and adjustment of such systems is possible from anywhere in the world.

2.3.3 Bluetooth

Bluetooth communication uses short-wavelength UHF radio waves (2.4 to 2.485 GHz), and references the standard IEEE 802.15.1. The Bluetooth protocol is managed by Bluetooth SIG.

The characteristics for Bluetooth are:

- Star network protocol
- High data rate
- Shorter distance operating range
- Medium power consumption

2.3.4 Zigbee

Zigbee is used in smart lighting, appliances and other products that involve wireless communication. The ZigBee protocol is maintained and developed by the ZigBee Alliance, which is an open, non-profit association of approximately 450 members.

The characteristics for Zigbee are:

- Mesh network protocol
- Low data rate
- Short distance operating range
- Low power consumption

2.3.5 Z-wave

The Z-Wave protocol operates in the sub-gigahertz frequency range, around 900 MHz and is designed with focus on low power consumption suitable for battery-operated devices and low-latency transmission of small data packets at data rates up to 100 Kbit/s. The Z-Wave protocol is managed by the Z-wave Alliance, which is an open consortium of 375 companies.

The characteristics for Z-wave are:

- Mesh network protocol
- Low data rate
- Short distance operating range
- Low power consumption

2.3.6 6LoWPAN

6LoWPAN is an acronym of IPv6 (IP = Internet Protocol) over Low power Wireless Personal Area Networks, and references the standard IEEE 802.15.4. The 6LoWPAN protocol is designed for low-power devices with limited data processing capabilities.

The characteristics for 6LoWPAN are:

- Mesh network protocol
- Low data rate
- Short distance operating range
- Low power consumption

2.3.7 Interoperability

Smart lamp systems including smart lamps, gateways[4], luminaires, controls, meters and management systems (*i.e.,* software) tend to rely on proprietary hardware and software.

In the home, smart lamp communication is performed by a number of wireless protocols (see above). However, even where communication uses the same protocol for different products, the user may still have to use different software applications (apps) to control each product. This lack of interoperability may result in the user being restricted to purchasing all products from a single manufacturer in order to ensure compatibility and easy management.

With the evolution of technology, features and software over time, even users relying on one manufacturer may have to make a decision to either start over or live with an existing, increasingly unsuitable or outdated smart lighting system.

Other standards/protocols are used in building automation systems for commercial buildings. Efforts to bring more standardisation and interoperability to the market are underway within manufacturers' alliances and international standardisation organisations, but most are organised around each communication protocol.

Lack of interoperability between different manufacturers' lighting products could represent a barrier for large scale market adoption of smart lighting, particularly in the residential sector.

[4] A component in the communication architecture for half of the smart lamp models tested for this study.

2.4 Four Types of Communication Architecture

Typically, a smartphone app is used to control the lamps with network access and wireless communication between the lamps via the star network protocols WiFi (high data rate, longer operating rate, relatively high power consumption) and Bluetooth (high data rate, short operating rate, lower power consumption) or the mesh networks protocols Zigbee, Z-wave, 6LoWPAN or others (low data rate, short operating rate, lower power consumption).

Some lamps are controlled by a dedicated remote control as user interface plus a proprietary star or mesh based network protocol as both user link and lamp link

Four kinds of communication architectures have been found in the smart lamp products tested by the organisations that have provided smart lamp test data.

The use of the four communication architectures is analysed in chapter 5.

2.4.1 Communication Architecture Type A

This architecture makes use of **WiFi** for the user interface and a **separate gateway** that transfers the communication to **another wireless communications protocol**, e.g., Zigbee, Z-wave or 6LoWPAN, used for communication to the lamps and between the lamps.

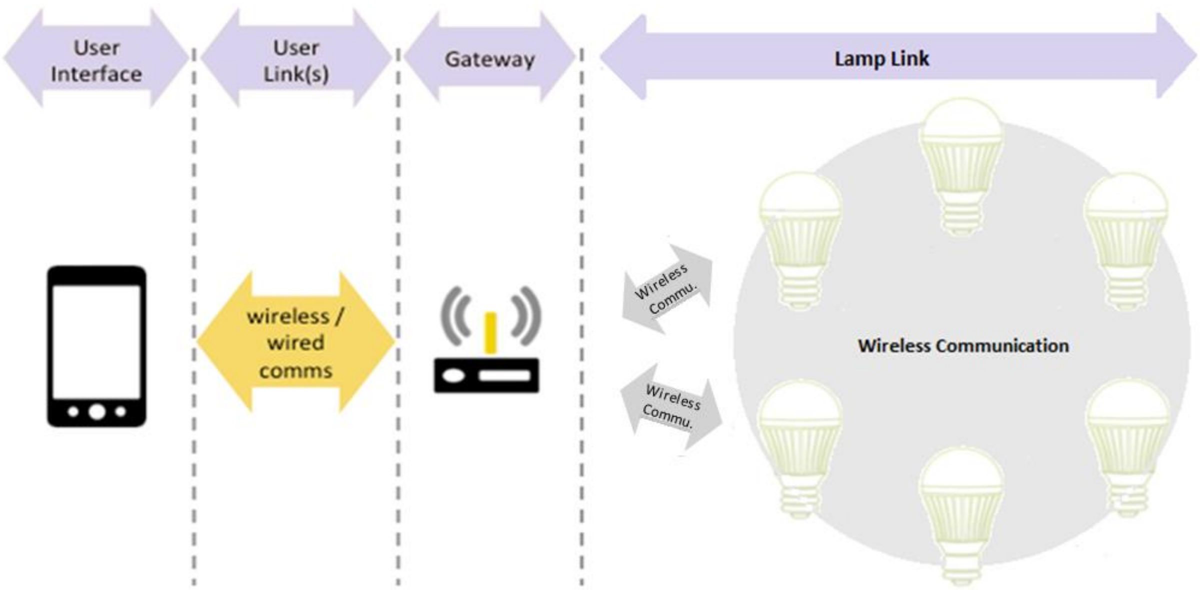


Figure 4. Communications architecture Type A using WiFi, gateway and another protocol

2.4.2 Communication Architecture Type B

This architecture is making use of the star based network **WiFi** or the star based network **Bluetooth** for both user link and lamp link. Use of Bluetooth is most common.

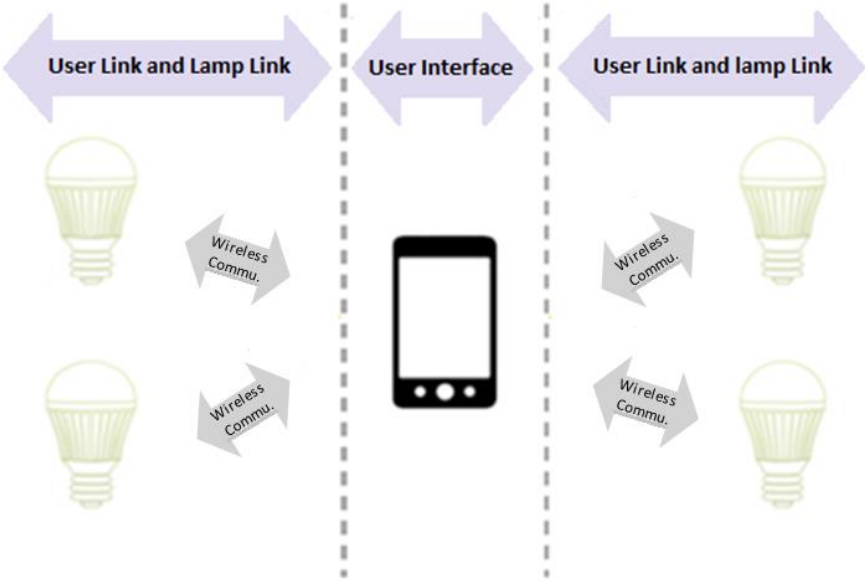


Figure 5. Communications architecture Type B based on either WiFi or Bluetooth

2.4.3 Communication Architecture Type C

This architecture is making use of **WiFi** for the user interface and one **gateway lamp** that transfers the communication to the other lamps by **another wireless communications protocol**, e.g., Zigbee, Z-wave or 6LoWPAN.

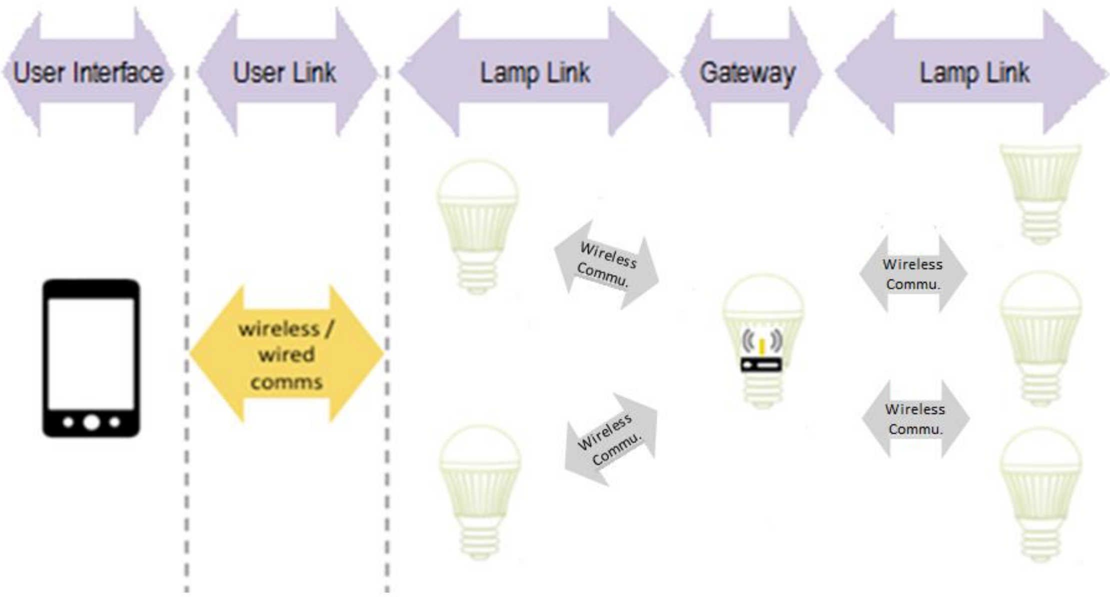


Figure 6. Communications architecture Type C using WiFi and one lamp including gateway that communicate to the other lamps using another protocol

2.4.4 Communication Architecture Type D

This architecture is making use of dedicated remote control as user interface plus a proprietary star or mesh based network protocol as both user link and lamp link.

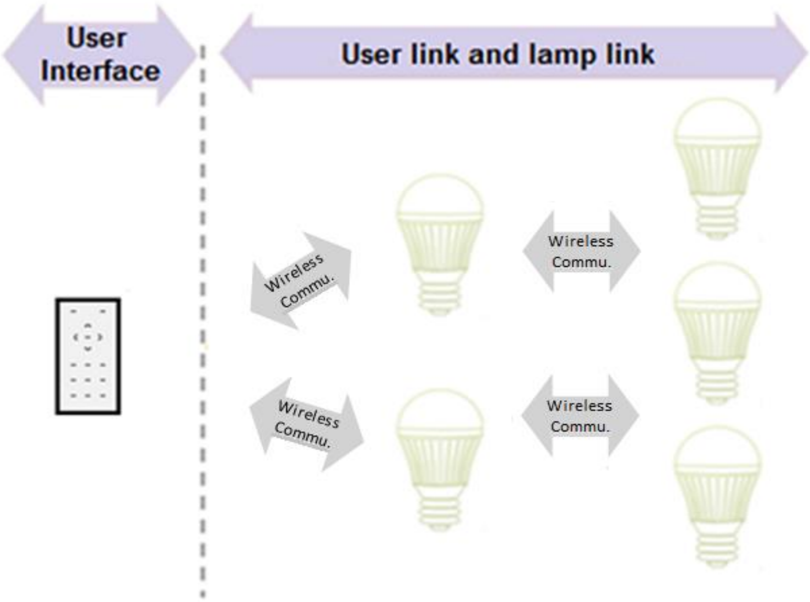


Figure 7. Communications architecture Type D using a remote control and a proprietary protocol

3 Product Information

When conducting tests on smart lamps, the information below in Table 2, should be recorded about each of the models under test.

Table 2. Product information to record

Subject	Description	What to record	Notes
Product and purchase	Identity	• Manufacturer • Model	
	Technical ID	• Cap/base • Shape • Size	
	Purchase information	• Date • Where (store name and location) • Price and currency	
Smartness	Product features	• Dimming • Colour tunability • Mood settings • Audio speaker for music from the lamp • Auto ON/OFF based on occupancy (light, PIR, sound activation) • Auto ON/OFF to simulate there are people in the building (theft measure) • Name and version number of the smartphone app • Other	Is the smart lamp part of a dedicated home automation system? (yes/no)
Gateway		• Rated power consumption • Max no of lamps per gateway	Only present in com. architecture A
Communication	User interface	• Wireless network structure with interface via: o smart-phone app, o remote control unit or o other medium	Included along with the lamp in the packaging? (yes/no)
	Protocol	• Protocol for user link o WiFi, Bluetooth • Protocol for lamp link o Star network (WiFi, Bluetooth) o Mesh network (Zigbee, Z-wave, WeMo, 6LoPLAN etc.)	Did you face start-up or communication protocol challenges?
Power Consumption	Power supply	• Rated power supply voltage range • Rated frequency range	
	ON mode	• Rated value on packaging/data sheet/ lamp	If possible, CCT for rated value
	STANDBY mode	• Rated value on packaging/data sheet/ lamp	Note if not provided
Light output	Luminous Flux	• Rated value(s) on packaging/data sheet/lamp	If possible, CCT for rated value(s)

Subject	Description	What to record	Notes
Colour quality	CCT (three options depending on the smartness of the lamp)	• One rated value on packaging/data sheet/lamp • A few rated values on packaging/data sheet/lamp • CCT range/interval	If max CCT > 6500 K, does the lamp comply with blue hazard testing requirements?
	RGB(W) lamp	• LEDs incorporated in lamp	Does the lamp incorporate red, green and blue LEDs which enable the user to select any light colour? (yes/no)
	CRI	• Rated value on packaging/data sheet/ lamp	Is CRI provided for a range of CCTs?
	Pre-set scenes	• Descriptions of the pre-set scenes offered	

4 Methodology for Smart Lamp Testing

The methodology outlined below is an interim test method for laboratories to conduct benchmark testing, and potentially for future compliance or enforcement testing. The steps of the test method are written in normal font while the *text in italics* provides optional additional steps and/or practical notes for the person conducting the test.

4.1 Product Sampling

A sample size of 1–3 lamps per model is sufficient for the benchmark testing as it is a priority to understand the performance range of products in the marketplace (and assess the potential energy usage impact) by testing as many lamp models as possible.

Note: Benchmark testing is very different from market surveillance or compliance and enforcement testing, where the public authorities define a minimum sample size based on statistical analysis. For example in the EU, the sample size is typically required to be 20 units of each lamp model selected for market surveillance testing.

4.2 Laboratory and Environmental Conditions

The laboratory and environmental conditions shall be as specified in CIE S025/E:2015, Section 4.2 "Laboratory and Environmental Conditions", unless other requirements are stated in another referenced standard within subsequent sections of this document.

4.3 Configuration for Test

The lamps shall be tested as supplied (i.e. out of the box) and/or in accordance with the initial set-up as specified for the consumers by the manufacturer.

Optional testing: Where it is possible to reset the lamp (to factory default settings) by a dedicated button or a switching sequence[5] the lamp should be retested after reset has occurred.

4.4 Operation

The lamps shall be operated by the user interface e.g. a smartphone, remote control or other device. It must be ensured that the lamps are working as intended, including functions such as dimming and colour tuning controlled by the user interface.

A user link (e.g. WiFi router or Bluetooth connection) is required.

4.5 Electrical Test Conditions

The test voltage and electrical power supply shall be as stated in CIE S025/E:2015, Section 4.3.1 "Test Voltage and Test Current" and Section 4.3.3 "Electrical Power Supply", unless other requirements are stated in another referenced standard within subsequent sections of this document.

[5] Some smart lamps do not have reset buttons, but instead are reset through a switching sequence of ON and OFF for specific periods of time. For example, the Osram Lightify LED lamp is reset by switching it ON for 5 seconds, then OFF for 5 seconds, and doing this five times. The light will then flash to confirm it has been reset to the factory default settings.

4.6 Stabilisation

Similarly to all other lamp types, the smart lamp needs to be stable before test measurements are executed. The lamp shall be stabilised for at least 30 minutes in the state in which it is to be measured. The lamp is considered to be stable if the relative difference between the maximum and minimum readings of electrical power and light output observed over the last 15 min is less than 0.5 % of the minimum reading within this 15 min period (CIE S 025/E:2015). If the lamp exhibits large fluctuations and the stabilization conditions are not met within 45 min of operation (150 min for LED luminaires), the measurement may be started and the observed fluctuations shall be reported. Pre-burning of the lamps to reach stabilisation may be applied. In that case, operation for at least 30 min is not needed and the stabilisation criteria over 15 minutes may be tested immediately.

For the STANDBY mode, the stabilisation might be reached very quickly, i.e. within 15 minutes of operation of the lamp.

Note: To observe the variation and stabilization of the power consumption, measurements shall be taken at a high sampling rate (e.g. every few seconds) and an average consumption calculated over the total period. For smart lamps, the stabilisation period might be longer since the lamps incorporate a transmitter and a receiver for communication. The receiver might be ON all the time (with a small duty-cycle) whereas the transmitter might broadcast two types of signals: 1) periodic supervision signals and 2) asynchronous signals related to specific events (e.g. triggered by sensors).

4.7 Measurement Period

It is recommended that the measurement for all lamp modes is done in one session in order to avoid the lamp cooling and to minimise the stabilisation periods every time the flux or CCT is changed. Stabilisation of voltage and luminous flux should be confirmed (for 15 minutes) after each change in operating configuration.

4.8 Electrical Measurement Equipment

All power measurements are to be conducted with measurement equipment (namely power meter, voltmeter, current meter) which satisfies the requirements of CIE S025/E:2015, Section 4.3.2 “Electrical Measurements”, unless more onerous requirements are stated in another referenced standard within subsequent sections of this document.

4.9 STANDBY Power Measurements

After operating the lamp in the default (out of the box) ON for 30 minutes, set the lamp to STANDBY and, after ensuring the lamp is stabilised (see section 4.4), measure the STANDBY power consumption in accordance with IEC 62301 – Household Electrical Appliances – Measurement of Standby Power.

4.10 Gateway Power Measurements

Gateways are only utilised for communication architecture Type A. Measure the power consumption of the gateway while at least one lamp is connected.

Note: The simple measurement of power consumption regardless of how many more lamps above one that the gateway supports appears to be sufficient due to results of testing of smart lamp models with communication architecture type A. In these tests, the gateway power consumption was measured over time while varying the number lamps supported by the gateway. In the tests, the result of this analysis was that the gateway power consumption was constant and was independent of the number of lamps connected.

4.11 ON Measurements

Photometric and colorimetric measurements of the lamp shall be carried out according to CIE S 025/E:2015, using a integrating sphere spectroradiometer.

Where the lamp includes extra services such as music from the lamp or features from the other 3 categories of smart lighting products (see section 1) and these are designed to be ON all the time, then the power consumption measurements shall include these extra services. Where they are designed to be switched ON by the consumer and/or only ON for a limited time, they should be excluded from the measurement.

4.11.1 Lamps with Adjustable Colour Temperature

Initially for smart lamps with adjustable colour temperature, the lowest and highest CCT achievable by the lamp shall be found in order to determine the nominal CCTs the lamp can provide.

In general for these lamps, the testing shall include the lowest and highest CCTs achievable by the lamp plus the nominal CCTs 2700 K, 4000 K, 5000 K and 6500 K and be conducted at maximum light output (mentioned in case the lamps are also dimmable). Table 3 shows the nominal CCTs.

Table 3. Nominal CCTs and associated x,y centre points for SSL products (ANSI C78.377-2015)

CCT (K)	2200	2500	2700	3000	3500	4000	4500	5000	5700	6500
x	0.5018	0.4806	0.4578	0.4339	0.4078	0.3818	0.3613	0.3446	0.3287	0.3123
y	0.4153	0.4141	0.4101	0.4033	0.3930	0.3797	0.3670	0.3551	0.3425	0.3283

For smart lamp models, five types of CCT setting are identified. For each of these types is below proposed a practical procedure for setting the CCTs:

- Discrete pre-set CCTs (often described as mood setting): Use these settings.
- Slide-bar with numeric notification: Slide with best possible accuracy.
- Slide-bar without numeric notification: Monitor the CCT with a calibrated illuminance/colour meter and slide with best possible accuracy.
- 2D colour space or colour wheel: Monitor the CCT with a calibrated illuminance/colour meter and adjust the touch with best possible accuracy for the region which represents the variation of white light (where the colour saturation is least, i.e. minimal chroma) e.g. the lowest CCT is below the red region and the highest CCT is below the deep blue region.
- CCT value (K) or the chromaticity coordinates can be entered: Enter the values.

4.11.2 Dimmable Lamps

Determine the minimum dimmed level achievable. The minimum dimmed level is determined as when either there is no light emitted (0 %) or the lamp no longer operates in an acceptable manner (e.g. fluctuating colour/light output or flicker). If this minimum dimmed level is less than 25 %, measure the lamp power (even if the minimum is 0 % light emitted).

For those lamps with adjustable light output (i.e. dimmable) testing shall be conducted with measurements for four dimming levels: 100 %, 75 %, 50 % and 25 % (or minimum dimmed level if this level is greater than 25 %) for the nominal CCTs of 2700 K and 5000 K if within the CCT limits of the lamp or else respectively the lowest and highest CCTs achievable by the lamp.

Dimming can be conveyed as the relative reduction in the light output or the lamp power. If this information is provided then it is to be reported.

For the different smart lamp models, three types of setting the dimmed level are found. For each of these is below recommended a practical procedure for setting the dimmed level:

- Pre-set percentage: Use these settings.
- Slide-bar with numeric notification: Slide with best possible accuracy to achieve the dimmed level.
- Slide-bar without numeric notification: Monitor the illuminance of the lamp at asset position with a calibrated illuminance meter and slide with best possible accuracy to achieve the relative illuminance.

4.11.3 Measurements

Table 4 provides an overview of combinations of CCT and dimming level to include. In case the lamp is only able to provide one of these features the amount of measurements will naturally be reduced according to this.

For each combination of CCT and dimming level, the measurements shall include:

1. Lamp power

   Total spectral flux after stabilisation (see section 4.4) from which the following parameters shall be calculated:

2. Luminous flux
3. CCT
4. Duv for the nominal CCTs
5. CRI

Table 4. ON Measurements (combinations of CCTs and lighting output) to be included in testing

		CCT											
		Min	2200	2500	2700	3000	3500	4000	4500	5000	5700	6500	Max
Lighting Output #)	100 %	Only CCT	O	O	M	O	O	M	O	M	O	M	Only CCT
	75 %				M			M		M		M	
	50 %				M			M		M		M	
	25 % ¤)				M			M		M		M	
	min	Only measure the luminous flux and the lamp power											

¤) Minimum dimmed level if this level is greater than 25 %. M= Mandatory O = Optional

#) Dimming can be conveyed as the relative reduction in the light output or the lamp power. If this information is provided then it is to be reported.

Optional testing

- *Measurements for all nominal CCTs (see Table 3).*
- *Measurements for CCTs that are of interest to the requesting party.*
- *For lamps producing white light from a blend of red, green and blue LEDs (RGB lamps) measurement of luminous flux and lamp power for each of the three pure colours red, green and blue. Please be aware that for many smart lamps, selection of a colour by an app is not precise as it is visual within a circle or square and often not on the blackbody locus curve.*
- *Measurement of CCT (e.g. every minute) from cold start until lamp has stabilised and eventually for restart of lamp after cooling.*
- *Test repeatability of selection of CCT under various control scenarios including approaching selected CCT from higher and lower CCTs.*

Note 1: The precision for selecting a CCT or colour by an app or user interface as well as the dimming level is normally not very precise as the selection is typically done in a small rendition of the CIE colour space map on a smart-phone screen with a relatively large fingertip.

Note 2: In case the smart lamp is able to provide a CCT > 6500 K, then the consumer has to be warned about the health hazard risk for blue light (there are some lamps providing up to 14000 K).

5 Results of Preliminary Smart Lamp Testing

The SSL Annex has compiled some test data on smart lamps purchased and tested in Annex Member Country lighting laboratories:

- 11 models purchased in the USA by Erik Page & Associates and tested at ITL Boulder,
- 7 models purchased by CLASP Europe and tested at the Swedish Energy Agency,
- 2 models purchased by the Australian government and tested by QUT Photometric Laboratory,
- 4 models purchased in Denmark and tested by DTU Fotonik,
- 24 models purchased and tested by the US Department of Energy.

In total, 34 different lamp models were tested. The sample size for each model tested is 1–3 lamps but several models are tested at different laboratories so grand total is higher for some models. Subsequently, the test results have to be handled as indicative measurements.

5.1 Stabilisation

Section 4.6 above describes that if the lamp exhibits large fluctuations and the stabilization conditions are not met within 45 min of operation, the measurement may be started and the observed fluctuations shall be reported.

Figure 8 [ref. 9] shows some examples of ON mode stabilisation measurements of luminous flux and power for three commonly used smart lamp models where stabilisation of the products was either not achieved or just achieved within 45 minutes according to the 0.5 % criteria (see section 4.6).

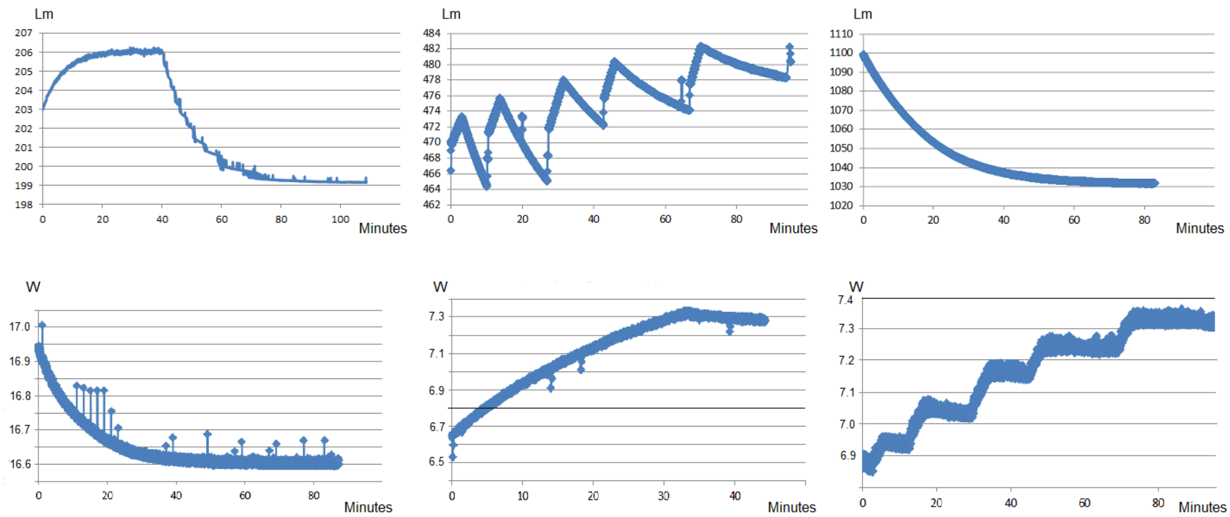


Figure 8. Examples of stabilisation measurements for luminous flux and power

5.2 Gateway Power Consumption

Some smart lamps with communication architecture Type A were tested to ascertain if a simple measurement of the gateway power consumption is sufficient, regardless of the number of lamps the gateway supports. The gateway power consumption was measured over time while varying the number lamps supported by the gateway.

Tests results revealed that the gateway power consumption was independent of the number of lamps connected. Figure 9 [ref. 9] shows the results for one of the products tested over a 40 second time period. The blue line shows the measured gateway power consumption while the green line shows the summated power for a varying number of lamps connected and ON.

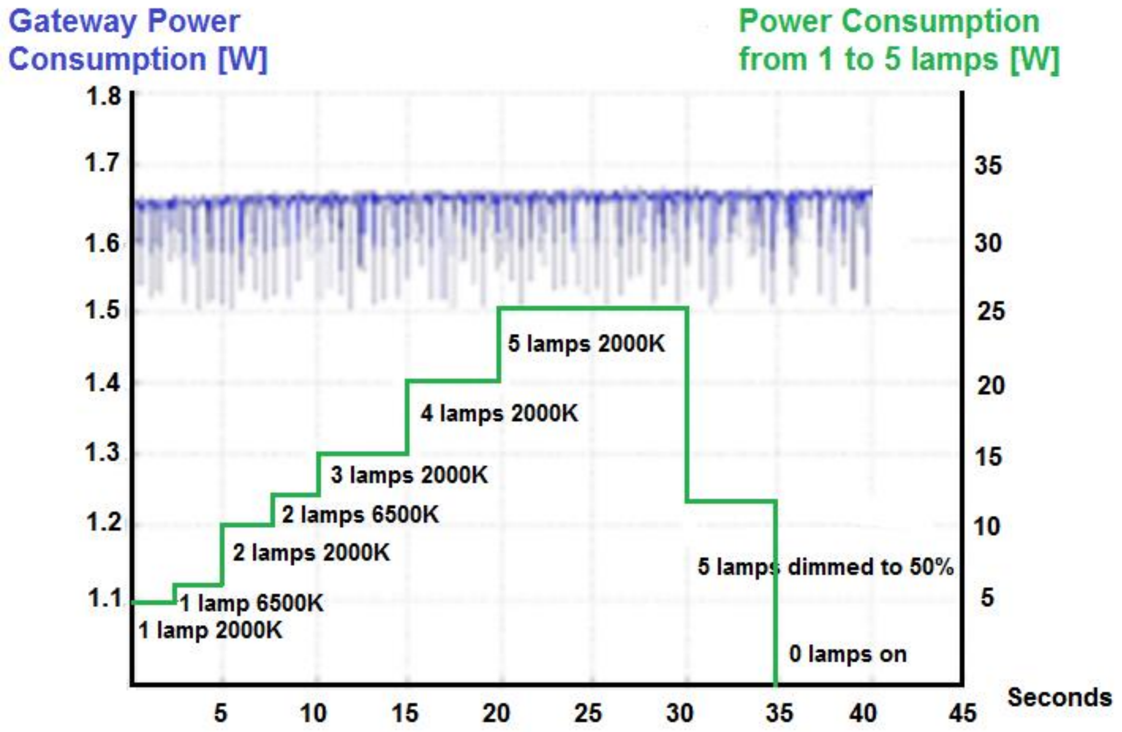


Figure 9. Nearly constant gateway consumption with a varying number of lamps in operation

5.3 Luminous Flux and Colour Temperature

The precision for selecting a CCT or colour (as well as the dimming level) by an app or user interface is normally not very precise. The selection of colour is typically done in a small rendition of the CIE colour space map on a smart-phone screen with a relatively large fingertip. Figure 10 [ref. 9] below shows two examples of measured luminous flux related to colour temperature for smart lamps without any dimming (100 % luminous flux). The manufacturer's rated luminous flux is respectively 810 and 1000 lumens.

For both lamps, the tests revealed the lumen output to be up to 40 % less than the rated value depending on the selected CCT, e.g. for the lamp with 810 lm rating, it only provides 500 lumens when the CCT is 2700 K. Typically, the manufacturers do not inform the buyers of the product's CCT for the rated luminous flux and power consumption but instead appear to state the maximum luminous flux over the selectable CCT range for the product.

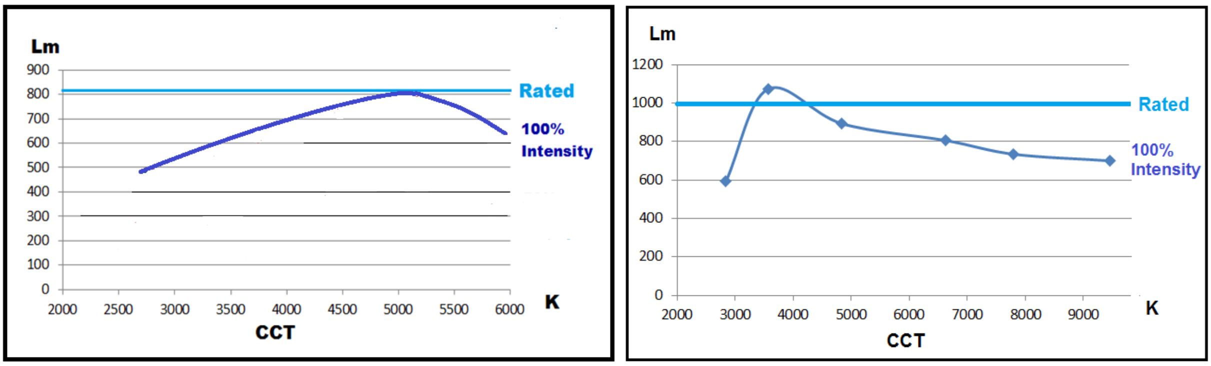


Figure 10. Two examples of measured total luminous flux as a function of CCT

5.4 Standby Power Consumption

The testing has revealed that the standby power consumption for the 34 different lamp models varies substantially between 0.15 W and 2.71 W as shown in Figure 11.

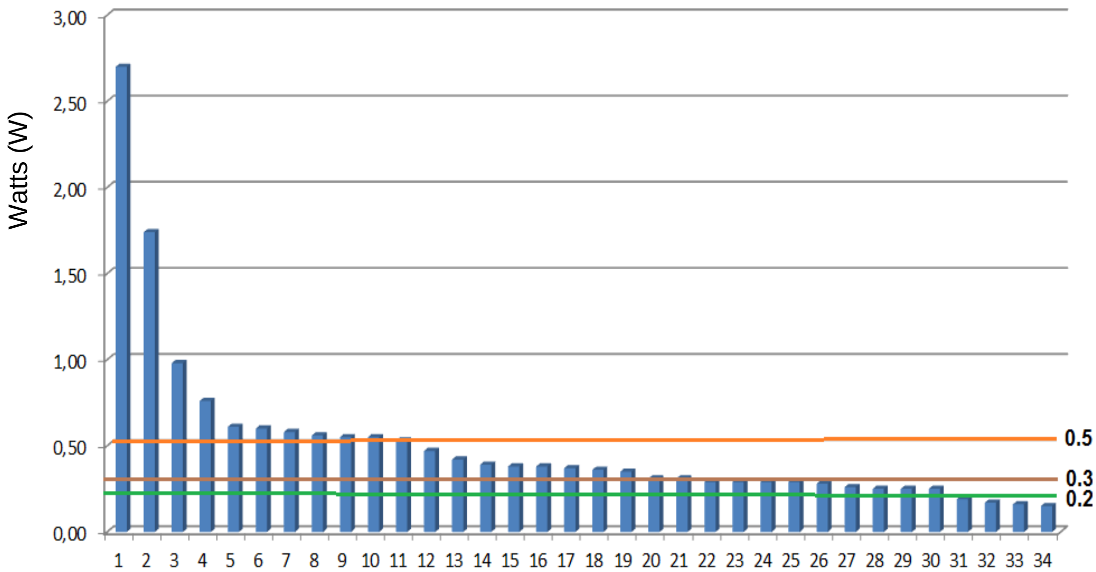


Figure 11. Standby power consumption for smart lamps

The average standby power consumption levels grouped by the different communication architecture types were found to be:

- Type A[6] using a gateway connecting to a different lamp link protocol: 0.38 W per lamp (average calculated from testing of 17 models). The average gateway power consumption is 1.6 W[7] (only measured for 3 of the 17 gateways: 1.7 W (lamp standby power 0.4 W), 1.4 W (lamp power standby 0.9 W) and 1.7 W (lamp standby power 0.4 W)). To illustrate the impact of multiple lamps, the

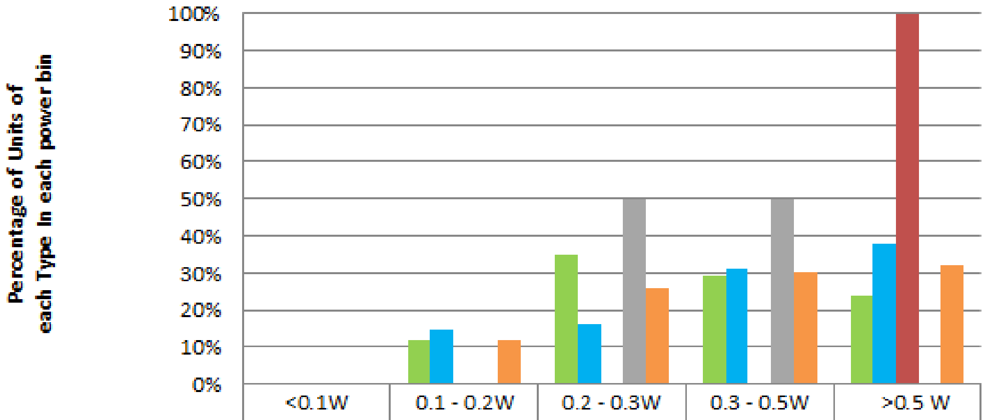
[6] For an explanation of the communication architecture classifications used in this report, please see section 2.1.

[7] The average gateway standby power consumption of 1.6 W is in line with measured power consumption of four home automation gateways [ref. 10]: 1.2 W, 1.7 W, 1.8 W and 3.3 W with an average of 2.0 W.

total average power consumption of the gateway per lamp is calculated to be 1.98 W for only one lamp connected, 0.70 W per lamp for five lamps connected or 0.41 W per lamp for fifty lamps connected (The manufacturers state their gateways can support up to 50 lamps).

- Type B using Bluetooth: 0.42 W per lamp (sample size of 13 models).
- Type C using WiFi: 2.22 W per lamp (sample size of 2 models).
- Type D with use of a dedicated remote control unit: 0.34 W per lamp (sample size 2 models). In addition to the lamp, there is small battery consumption (for the remote control unit).

Figure 12 shows the standby power consumption divided on power bins.



	<0.1W	0.1 - 0.2W	0.2 - 0.3W	0.3 - 0.5W	>0.5 W
Type A	0%	12%	35%	29%	24%
Type B using Bluetooth	0%	15%	16%	31%	38%
Type C using WIFI	0%	0%	0%	0%	100%
Type D with remote control unit	0%	0%	50%	50%	0%
All	0%	12%	26%	30%	32%

Figure 12. Standby power consumption analysis – proportion of models in each power bin

The user interface is a smartphone app for all smart lamps except the two lamps where a remote control unit is used.

For architecture Type A, the protocol Zigbee is used in most of the models tested, while the Z-wave and 6LoWPAN are used in the remaining few models. There is not enough data to calculate and compare average standby power consumption for products using these three protocols. The second highest standby power consumption per lamp would normally be for architecture Type A, but it is dependent on the number of lamps the gateway supports.

Architecture Type C (using WiFi all the way to the lamp) is the fastest communication solution but our initial findings show that the standby power consumption is higher for this architecture.

The lowest average standby power consumption appears for the architecture Types B and D.

5.5 Energy Consumption for Smart Lamps Providing 200–1000 lm

In homes in IEA 4E SSL Annex member countries, most lamps are used 1–2 hours/days [ref. 2].

When the lamp operation time is 1 hour per day (and 23 hours in standby mode), on average 51 % of the yearly consumption is used in standby mode. For 44 % of the lamps, the standby consumption is over 50 % of the total consumption.

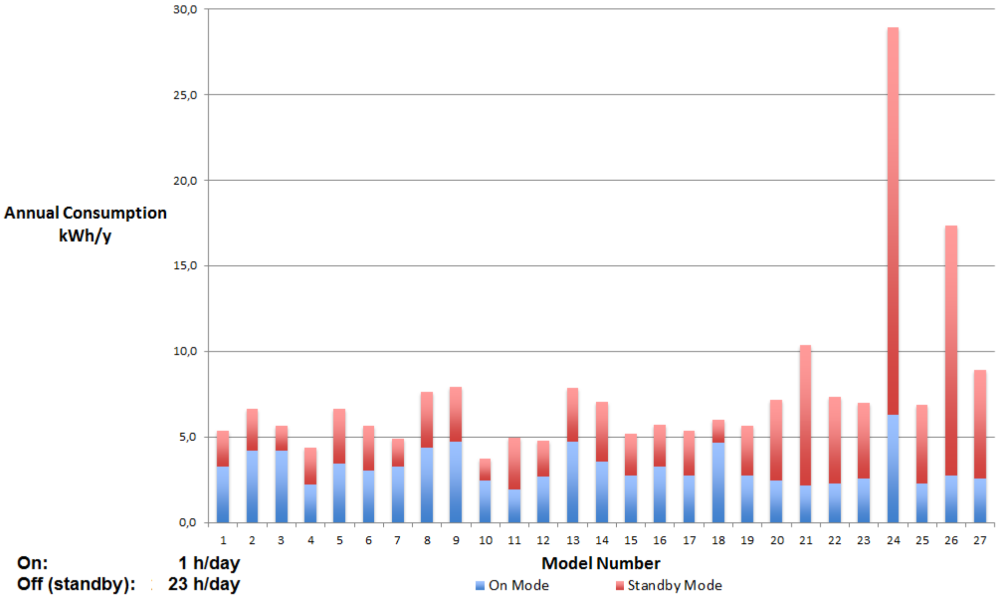


Figure 13. Annual energy consumption for 27 smart lamps models in operation 1 hour/day

When the operation time is increased to 2 hours per day, on average 35 % of the energy consumption is used in standby mode (for 19 % of the lamps over 50 % of the consumption).

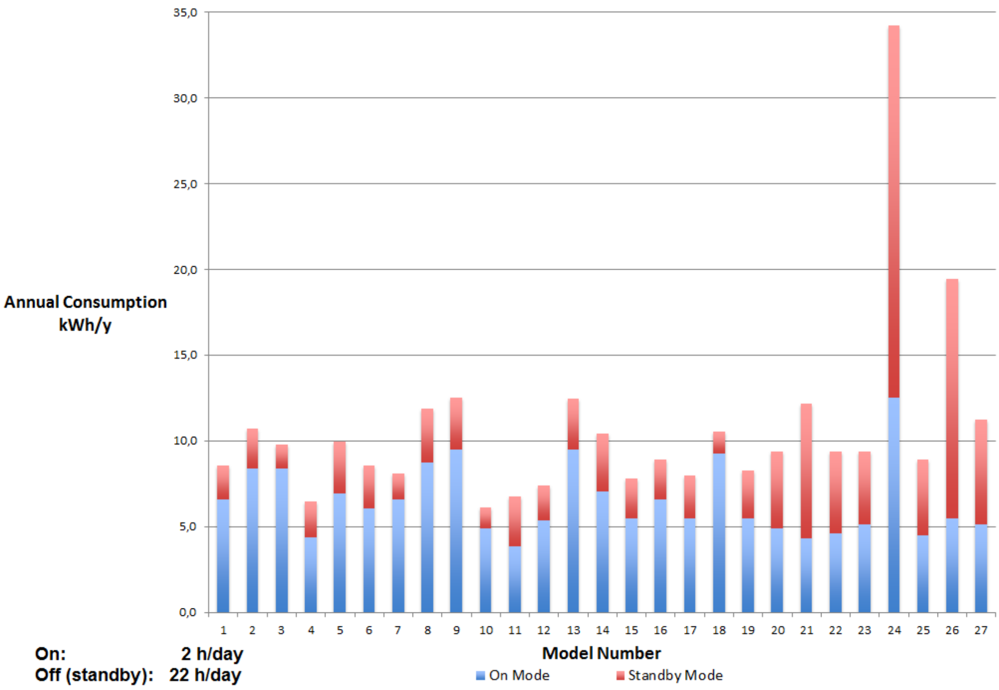


Figure 14. Annual energy consumption for 27 smart lamps models in operation 2 hours/day

The found high standby energy consumption is similar to the experience with other electronic products where the manufacturers first focused on incorporating the new features into the products before they paid attention to reducing the standby power [ref. 11 and 12].

5.6 Energy Consumption for Decoration Smart Lamps Providing 50–75 lm

Smart lamps with low lumen output seem to be intended mainly for decorative applications rather than general illumination. In any given decorative installation, there could be many of these, so their energy consumption would also be important.

When the lamp operation time is 1 hour per day (and 23 hours in standby mode), on average 71 % of the total daily energy consumption is used in standby mode.

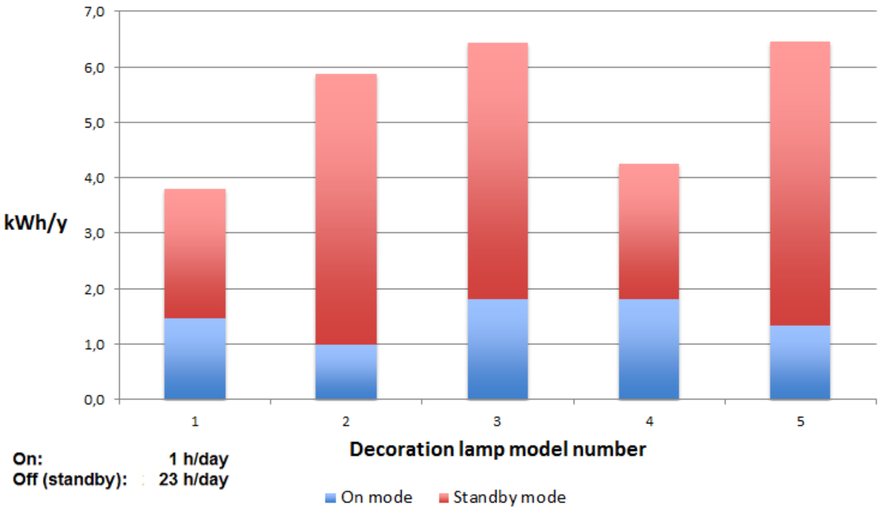


Figure 15. Annual energy consumption for 5 decoration smart lamps in operation 1 hour/day

When the operation time is increased to 2 hours per day, on average 54 % of the energy consumption is used in standby mode.

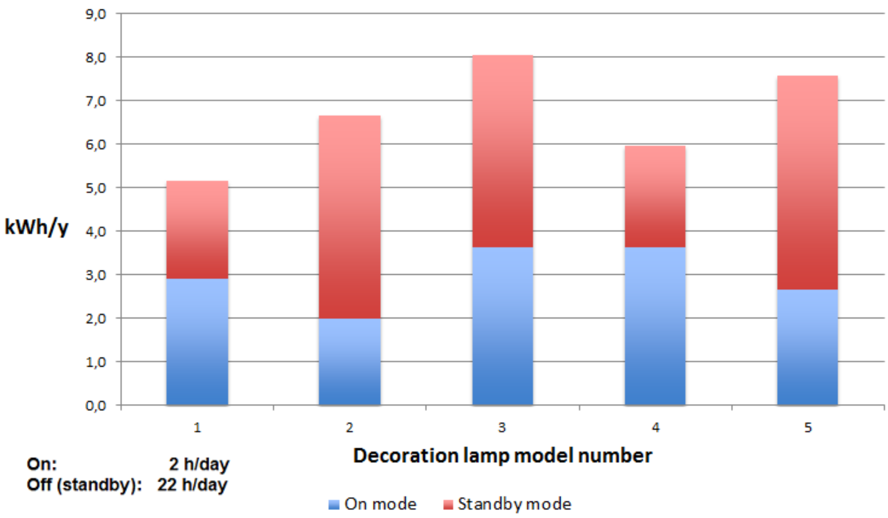


Figure 16. Annual energy consumption for 5 decoration smart lamps in operation 2 hours/day

5.7 Efficacy for Smart Lamp Providing 200–1000 lm

For the ON mode, the lamp efficacies range between 34 and 87 lm/W which is lower than for standard LED lamps models of equivalent light output operated by the normal on/off switch due to the additional internal electronic components associated with the 'smartness'.

When the lamp operation time is 1 hour per day (and 23 hours in standby mode), the overall efficacy (see section 2.1) varies between 9 and 51 lm/W, with an average 30 lm/W. For four of the lamp models tested, the overall efficacy is lower than the efficacy of incandescent lamps.

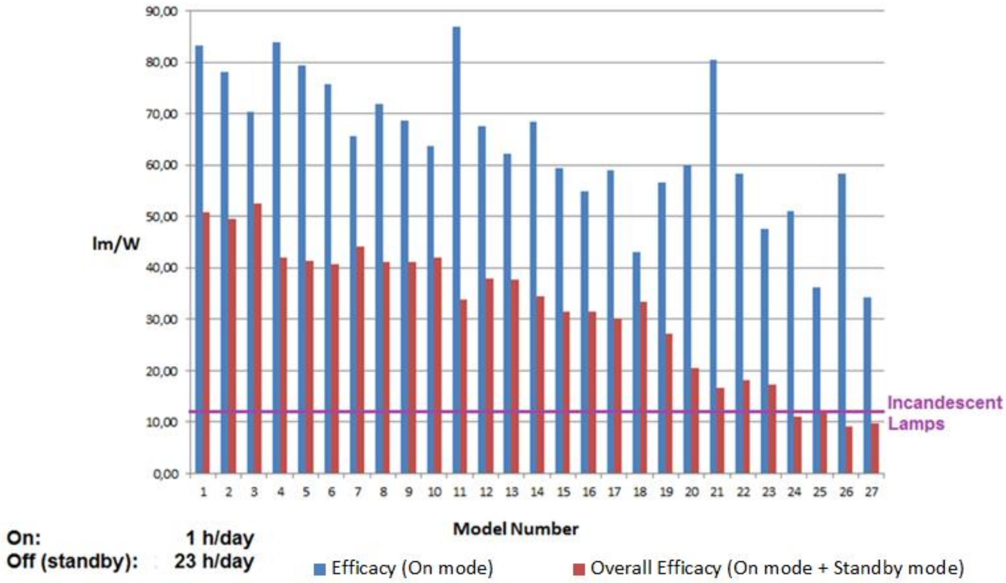


Figure 17. ON efficacy and overall efficacy for 27 smart lamps models in operation 1 hour/day

When the lamp operation time is increased to 2 hours per day (and 22 hours in standby mode), the overall efficacy varies between 16 and 64 lm/W, with an average of 40 lm/W.

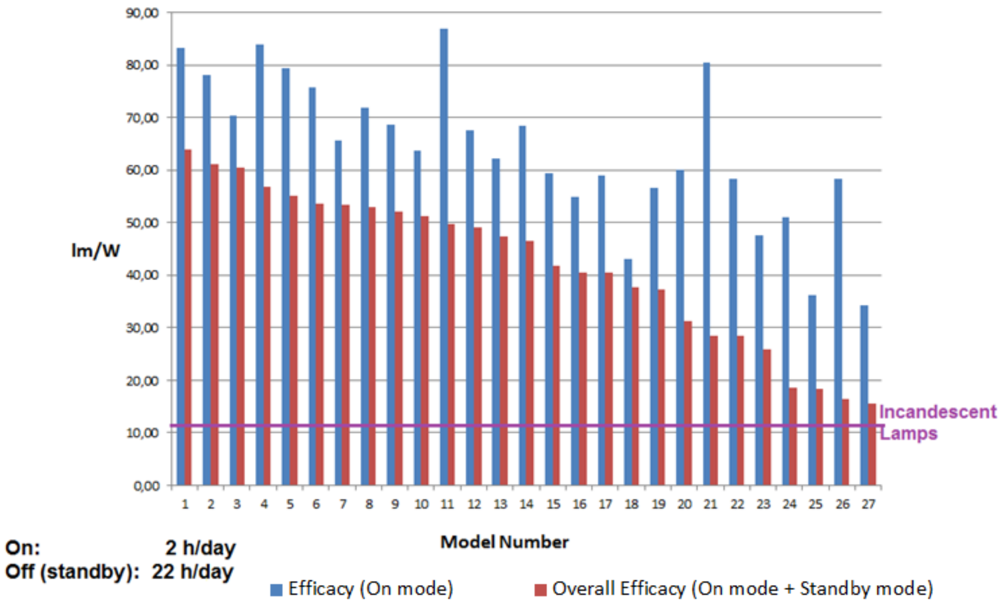


Figure 18. ON efficacy and overall efficacy for 27 smart lamps models in operation 2 hours/day

5.8 Efficacy for Decoration Smart Lamps Providing 50–75 lm

The testing of five decoration smart lamp models revealed that the ON efficacy varied between 9 and 20 lm/W. This is very poor compared to standard LED lamps. When the operation time is 1 hour per day (and 23 hours in standby mode), the overall efficacy was found to be very low between 3 and 5 lm/W.

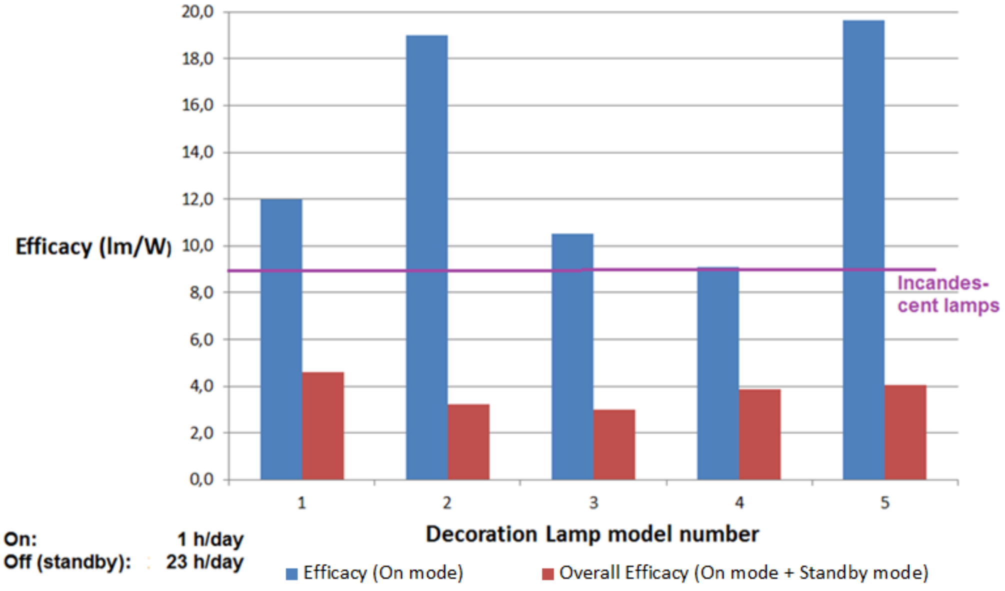


Figure 19. Efficacy for 5 decoration smart lamps in operation 1 hour/day

When the operation time is increased to 2 hours per day (and 22 hours in standby mode), the overall efficacy varied between 5 and 7 lm/W which is still substantially lower than the efficacy of incandescent lamps.

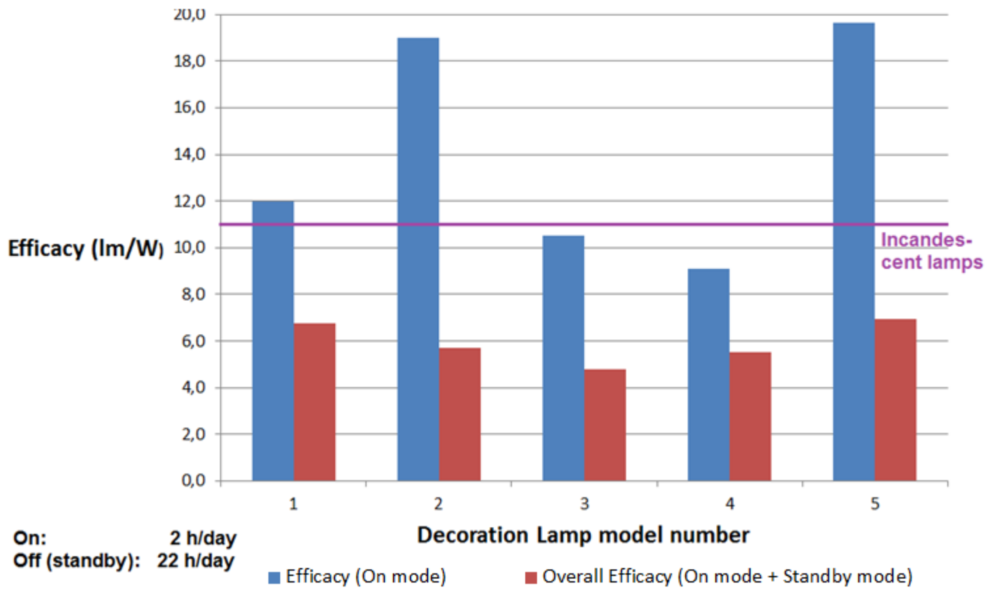


Figure 20. Efficacy for 5 decoration smart lamps in operation 2 hours/day

5.9 DimTone Lamps

A new type of LED lamp called "DimTone" emulates the shift in CCT that occurs when an incandescent or halogen lamp is dimmed. In other words, as the light output is reduced, the colour shifts to lower CCT with more orange and red content.

DimTone lamps are controlled by an external dimmer when the lamp is in the ON mode, and there is thus no standby power consumption.

Figure 21 shows how the LED DimTone lamp gradually changes CCT from 2727 K (260 lm) to 2200 K (20 lm). For comparison, in that figure is shown the dimming of a 40 W incandescent GLS lamp, which changes its CCT from 2609 K (375 lm) to 2060 K (26 lm).

The dimming with change of CCT has an influence on the efficacy where the LED DimTone lamp starts at 84 lm/W (100 % luminous flux) and decreases to 26 lm/W (8 % luminous flux), while the incandescent lamp starts at 9.1 lm/W (100 % luminous flux) and decreases to 2.4 lm/W (13 % luminous flux).

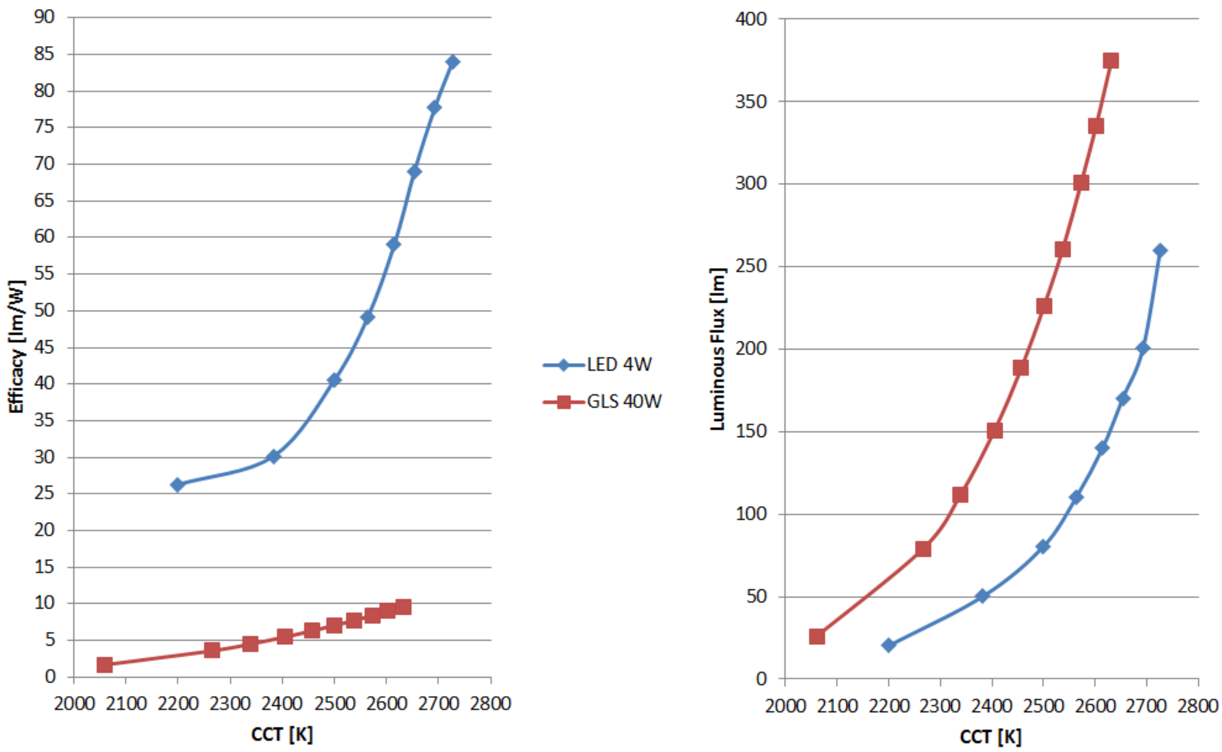


Figure 21. Comparison of DimTone LED lamp and 40 W incandescent lamp

6 Large Market Potential

The market potential of smart lighting is extensive, once the platform enabling functionality has been established. These smart lighting products can also be used in other applications such as museums, exhibition halls, shopping centres and supermarkets, where the lamps might be used as WiFi or LiFi nodes to help consumers with smart phones to navigate a building or find products in a store. In these premises, the daily hours of operation is typically high and the overall efficacy (see section 1.2.2) is thus relatively high but then control features might be used to realise energy savings by turning off lights which would normally remain on. The interaction between the smart lights and smart phones could activate visual and aural information for self-guided museum tours or detailed product information in a store.

The opportunities and applications are virtually limitless. For this reason, the IEA 4E SSL Annex feels it is important to study standby power consumption and raise awareness about this extra energy consumption which is a necessary aspect of the new smart services. In just a few years, there could be dozens of wirelessly controlled lamps in a single home.

Smart lamps and luminaires appear also integrated with smart home services. As an example of this development, Sony partnered with Toshiba in January 2016 [ref. 7] to publish information about their latest new multi-functional luminaire set to go on sale in Japan in 2016. The services and features included in this luminaire are:

- Illumination of the room in any colour of light available on the visible spectrum;
- Sensor that detects when someone is in the room and switches the luminaire on;
- Sensor that measures temperature and humidity and communicate that information to air conditioning and thermostats;
- Feature that turns on the television when someone walks in, including a sound/speaker system;
- Burglar alarm by doubling the overhead light if an uninvited guest enters;
- App which serves as a home intercom system receiving voice commands regarding other gadgets under its control.

Figure 22. Sony multifunctional smart luminaire

Other non-lighting services include music, boosting of WiFi signal in areas where the router does not work, cameras, voice activated services, sound activated text message services, smoke alarm, intruder alarm, baby monitor, etc.

Sales of individual smart home devices might double within less than 10 years [ref. 13] and many of us might be paying for an entire smart home services package just as we currently do for our Internet connection and energy utility services. Service providers are already bundling established devices as an integrated package[8]. The Sony luminaire and similar products might become hubs for controlling the different services.

[8] E.g. Nest Thermostats and Philips HUE lights

7 The Challenge for Policy Makers

The total energy impact of smart lamps is difficult to predict, as it is dependent on the functionality developed and the deployment model employed by the suppliers, as well as the user acceptance.

The first measurements conducted and reported in this study indicate that smart lighting may increase the lighting energy consumption considerably (particularly in residential applications) as experienced with early generations of other appliances with network capability and standby mode. What seems like a relatively small standby wattage might significantly increase the annual energy consumption due to the number of smart lamps installed.

It seems desirable to regulate the standby power consumption for smart lamps at an early stage in order to provide a limit on power consumption under which the lamp functionality may be developed, but without unduly limiting innovation.

At present, there are no definitions of any efficiency based metrics that adequately capture both the potential functionality and standby modes of smart lamps weighted by the number of hours in the two modes. There is also no international or regional test methodology against which to measure these efficiency based metrics and smart features as part of a possible regulation. This clearly presents a significant challenge for a policy maker. As discussed earlier, the US DOE recently finalised a test procedure for LED lamps [ref. 14] which references IEC 62301 for the standby mode test method, but this procedure does not include a calculation of the overall efficacy.

If policy makers were to adopt a 'wait and see' strategy before establishing policies to encourage lower standby power consumption, it could result in higher energy consumption overall due to the market developing without consideration for lowering the energy consumption and the long lifetime for the products.

At this time, it is critical to develop suitable test methods and consider voluntary and regulatory measures as the sales of smart lamps are expected to increase rapidly as high prices come down. Hence, development of an interim test method and associated regulation is becoming more urgent.

7.1 Methodology for Smart Lamp Testing

The IEA 4E SSL Annex has outlined a temporary measurement approach in this report for test laboratories to conduct indicative testing, and later for compliance or enforcement testing. This is coordinated with IEA EDNA Annex because EDNA has developed an approach for collection of indicative non-laboratory approximate measurements in shops and elsewhere.

7.2 Maximum Standby Power Limits

The IEA 4E SSL Annex is working to raise awareness of standby energy consumption, and has issued a press release (http://ssl.iea-4e.org/news/smart-lighting) and given a number of presentations at conferences, seminars and workshops on this topic [ref. 3, 4, 5, 6 and 7].

There are some governments already looking at voluntary and regulatory measures relating to maximum standby power consumption of smart lamps around the world:

- The latest version of the voluntary US ENERGY STAR specification includes a requirement of a maximum standby power consumption of 0.5 W.
- The on-going revision of the EU lighting regulation will come into effect from 2018: The first draft of the regulation proposes a requirement of maximum 0.5 W. Several member countries commented on this and suggested a lower maximum requirement as well as gradual lowering of the maximum standby power consumption by a three stage model.
- In the IEA 4E SSL Annex Task 6 quality and performance tiers update published in 2016, the requirements for maximum standby power consumption are: 0.5 W for Tier 1, 0.3 W for Tier 2 and 0.2 W for Tier 3 [ref. 1].

7.3 Rated performance for Smart Lamps

In several cases, the manufacturer reported a relatively high rated efficacy which is measured at a cold CCT (e.g., greater than 5000 K). The luminous flux might be very different for warm colour temperatures around 2700 K, which is the preferred CCT in some parts of the world.

IEA 4E SSL recommends that governments require the manufacturer to report the rated luminous flux as well as the efficacy for the two correlated colour temperatures of 2700 K (warm colour) and 5000 K (cold colour) to reflect the different cultural preferences around the world. DOE requires a manufacturer to report CCT and conduct tests at reported CCT values, but it does not require information for specific CCT points.

7.4 Overall Efficacy

The IEA 4E SSL Annex has defined a new key term: overall efficacy.

The overall efficacy express luminous flux (the light output) per unit energy consumed taking into consideration both the energy consumed in ON plus in STANDBY. The overall time period has to minimally be per day, but the accuracy improves with longer periods such as a week or a full year.

It is suggested that policy makers state overall efficacy performance requirements for smart lamps.

8 References

[1] The SSL Annex works internationally to support efforts at a national and regional level by addressing the main challenges with SSL technologies in order to develop a consensus on harmonised approaches to SSL performance and quality. The work of the SSL Annex spans a wide range of initiatives including guidance for policy makers, quality and performance tiers and support for laboratory accreditation, see http://ssl.iea-4e.org/. The SSL Annex is collaborating with the IEA EDNA (Electronic Devices and Networks) Annex which focuses on all kind of network connected devices including smart lamps, see http://edna.iea-4e.org/about.

[2] Assessment of the initial situation in the participating countries, PremiumLight, IEE/11/941/SI2.615944, Energy piano, 2013.

[3] "Smart" Wireless Lighting also needs to be Energy Smart, IEA 4E SSL press release, 22 April 2015. http://ssl.iea-4e.org/news/smart-lighting

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[5] Not so clever when they are off: standby power use in smart lamps, Erik Page, Steven Beletich, Stuart Jeffcott and Earmon Kummert, ECEEE Summer Study Proceedings, June 2015.

[6] Is Smart Lighting Energy Smart?, Casper Kofod, EEDAL, August 2015.

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[8] Latest Sony gadget sheds light on smart homes, Relaxnews, January 14, 2016.

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[11] Pulling the plug on Standby power, The Economist, March 9th 2006, including LBNL data.

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[13] Increasing Use of Smart Electronic Devices in Home Environments Drives Global Home Networking Devices Market, http://www.transparencymarketresearch.com/article/home-networking-device-market.htm, Mar. 2016.

[14] DOE, FEDERAL REGISTER, Vol. 81, No. 127, 10 CFR Parts 429 and 430, Energy Conservation Program: Test Procedures for Integrated Light-Emitting Diode Lamps; Final Rule, July 1 2016.