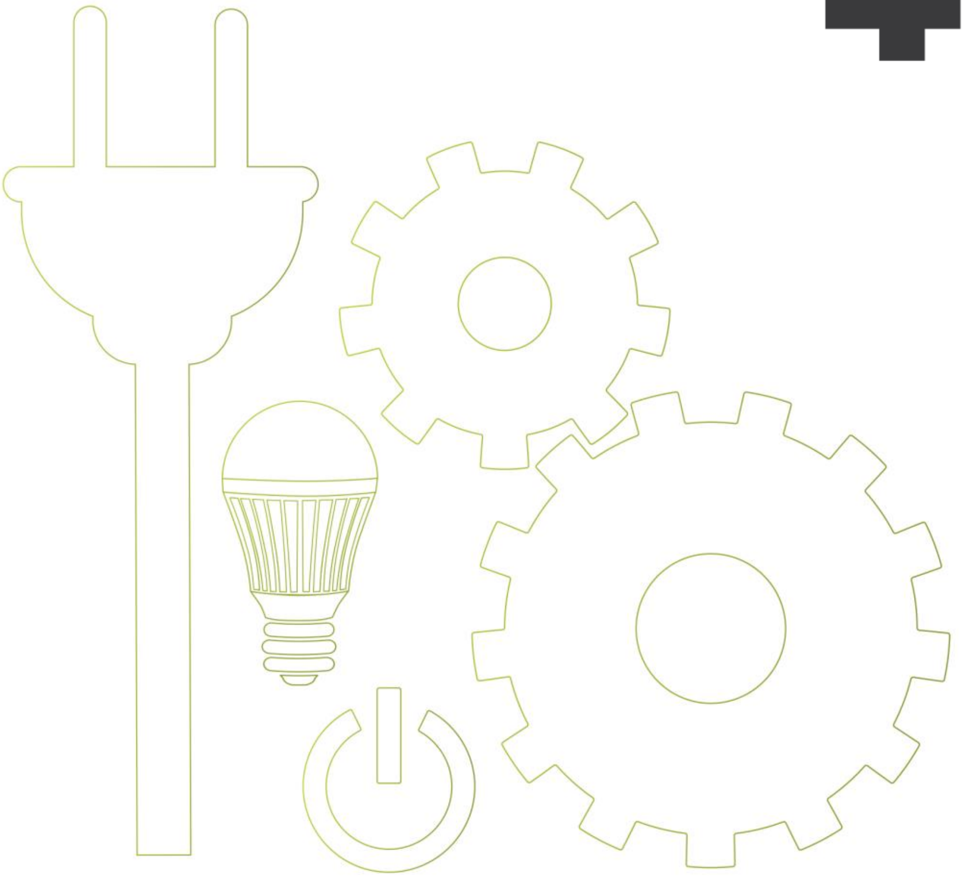

Solid State Lighting Annex: Task 7: Smart Lighting – New Features Impacting Energy Consumption

Second Status Report

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

15 NOVEMBER 2022

IEA 4E Solid State Lighting Annex

Task 7: Smart Lighting – New Features Impacting Energy Consumption

Second Status Report

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About the IEA 4E Solid State Lighting (SSL) 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 promote energy efficient lighting and to implement quality assurance programmes for SSL lighting. This international collaboration currently consists of the governments of Australia, Denmark, France, the Republic of Korea, Sweden and the United Kingdom. Information on the 4E SSL Annex is available from: https://www.iea-4e.org/ssl/

About the International Energy Agency's Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E)
Fifteen countries from the Asia-Pacific, Europe and North America have joined together under the forum of 4E to share information and transfer experience in order to support good policy development in the field of energy efficient appliances and equipment. 4E focuses on appliances and equipment since this is one of the largest and most rapidly expanding areas of energy consumption. With the growth in global trade in these products, 4E members find that pooling expertise is not only an efficient use of available funds, but results in outcomes that are far more comprehensive and authoritative. Launched in 2008, in view of its achievements during the first and second five-year terms, the IEA endorsed 4E's application for a third term that will run to 2024. https://www.iea-4e.org/

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Executive Summary

Smart lamps and luminaires are common in today's lighting market. Smart lighting provides an opportunity for the consumer to benefit from wireless control of lighting products, e.g. by dimming, colour tuning and scheduling. These functions can provide energy saving but they do also require energy consumption to supply standby power and gateways. In 2015, the SSL Annex began to assess these lighting products including the energy impact utilising the 'smart' functions plus the communication protocols and gateways used.

In 2016, the first SSL Annex status report found a large variation in the standby power consumption from 0.15 to 2.70 W with an average of 0.50 W. These findings were based on indicative measurements from laboratories in Australia, Europe and the USA. It was clear that design improvements in terms of reduced standby power were possible for many of these products. For a typical 11 W lamp with a 0.50 W standby power that is turned ON for one hour per day, the standby energy consumption accounted for 51 % of the total energy consumption. For the same lamp turned ON for two hours per day, the standby consumption accounted for 35 % of the total energy consumption.

Based on these findings, the SSL Annex updated its recommended quality and performance requirements in 2016 with maximum standby power limits of 0.5 W for Tier 1, 0.3 W for Tier 2 and 0.2 W for Tier 3 [ref. 1]. In the years that followed, a maximum standby power consumption of 0.5 W was implemented in the US ENERGY STAR programme, the EU Ecodesign regulation, and regional and national standards in several African countries. Furthermore, this maximum standby power consumption has also been proposed for an Australia/New Zealand lighting regulation (taking effect from 2024).

This second SSL Annex Smart Lighting report includes:

- Guidance on how to test the smart lighting products, providing an update of the test method included in the first status report;
- Standby power analysis based on measurements performed in the period 2015-2020 including 236 smart lamps/luminaires coming from 67 different manufacturers;
- An analysis on how dimming and colour tuning influences efficacy and luminous flux;
- Impact on standby power consumption when the product becomes more complex by addition of new features[1], sensors, data processing, network functions and integration into home automation systems; and
- An assessment of smart lighting market barriers including user-friendliness, interoperability, consistency, open systems, standards, and connection/co-operation with existing wired control systems. The report describes how industry is working to simplify the products/systems, e.g. by control via smart buttons, voice and/or home automation, more user-friendly interfaces, plug and play and interoperability with wired lighting control systems.

[1] Several of the new features incorporated are non-lighting functions e.g. WiFi booster, camera, music from the lamp/luminaire, data logging, use of LiFi and providing communication for non-lighting features by connected lighting networks.

The second status report finds the standby power varied between 0.08 W and 3.5 W with an average (mean) of 0.51 W and a median of 0.39 W. 72% of the products had standby power ≤ 0.5 W with an average 0.33 W. Only 6% of the products had standby power ≤ 0.2 W with an average 0.16 W.

The smart lamps/luminaires with standby power > 1 W were products sold in Asian countries (with no standby power regulation) or products that incorporated non-lighting related features such as cameras, WiFi boosters and/or speakers. These features are typically always ON without the possibility for switching them OFF. It is recommended that manufacturers: (1) make it possible to switch these non-lighting features ON and OFF, and (2) consider using the wake-up standby concept for these features.

In 2019, California implemented a maximum standby power limit of 0.2 W. By July 2022, the California database of compliant products contained 558 certified smart lighting products with standby power of ≤ 0.2 W, including lighting products from all the major manufacturers. This policy measure in California seems to have also impacted the rest of North America, as 81% (504 products) of smart lighting products listed in the ENERGY STAR database have standby power ≤ 0.2 W.

The lower standby power consumption in North America appears primarily to be achieved by use of the IEEE Wake-Up Radio concept which is able to lower the standby power to 0.01 W or less without limiting features or constraining innovation. Analysis in this report demonstrates that at the level of 0.01 W (and below), the standby power consumption is no longer a major concern. Indeed, reducing smart lighting product standby power to this level would capture significant energy savings.

Many smart lighting products include a dimming function, and for many products the efficacy decreases with increased dimming. To determine energy savings through dimming, manufacturers would have to declare the efficacy at multiple dimming levels, which should include at least 25%, 50% and 75% of light output.

Many products also include a colour-tuning function, where the correlated colour temperature (CCT) can be adjusted. In most cases the declared luminous flux is at a CCT of 4000 K while the luminous flux may be much lower at a warm colour temperature around 2700 K. But there are also smart lighting products that offer nearly constant lumen output for the different colour temperatures. Variations in luminous efficacy have also been measured with colour temperature changes. It is recommended that manufacturers declare the luminous flux, power consumption and luminous efficacy at both a warm colour (2700 K) and a cool colour (4000 or 5000 K) to cover the different CCT preferences around the world. Manufacturers should also note any CCT ranges where the luminous flux is less than 70% of the maximum achievable luminous flux. The ideal situation would be if they declared performance at five CCTs: 2200, 2700, 4000, 5000 and 6500 K.

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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
DALI	Digital Addressable Lighting Interface (DALI) is a trademark for network-based products that control lighting
DiiA	The Digital Illumination Interface Alliance (DiiA) is an open, global consortium of lighting companies that aims to grow the market for lighting-control solutions based on DALI technology
DOE	US Department of Energy
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)
HCL	Human Centric Lighting is the art of creating lighting that mimics the natural daylight which drives our bodily functions. It enhances human performance, comfort, health and well-being.
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute for Electrical and Electronic Engineers
IEFT	Internet Engineering Task Force
IoT	Internet of Things, objects embedded with sensors, processing ability, software, etc. that connect and exchange data over the Internet or other networks
LED	Light Emitting Diode
lm	lumen
OEM	Original Equipment Manufacturer
P_{st}^{LM}	Short term flicker metric for visible flicker at frequencies below 80 Hz
PNNL	Pacific Northwest National Laboratory, USA
RGB	Red Green Blue (referring to colour mixing LED products)
SSL	Solid State Lighting
SVM	Stroboscopic Visibility Measure, for the higher frequency stroboscopic effect
UK	United Kingdom
USA	United States of America
W	Watts
Zhaga	International organisation, founded in February 2010, establishing industry specifications of interfaces for components used in LED luminaires

1 Introduction

Smart lighting developed following the rapid improvements in both wireless communication and LED lighting. Smart lighting started with key functions such as colour tuning, dimming and scheduling when brightness and colour changes over time. Later, as shown in Figure 1, features were added including:

- Control by activation sensors (e.g. occupancy, sound, daylighting, camera …);
- Processing (lighting control, control of other services (e.g. speaker) plus data logging, analysis and reporting); and
- Network functions e.g. WiFi boosting, integrating with other services (IoT) and wired lighting systems (DALI), and integration in home automation systems.

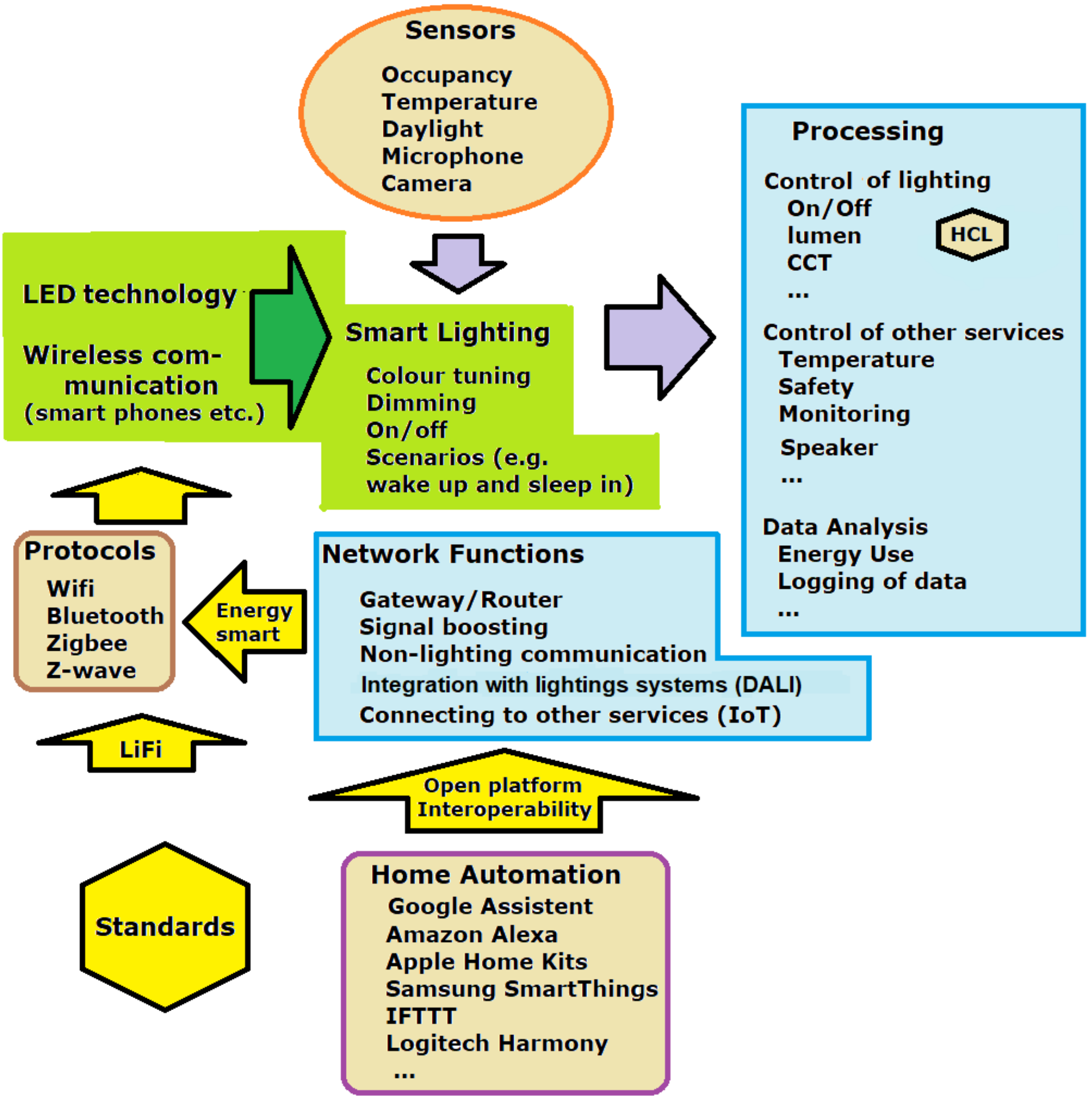

Figure 1. Smart lighting has developed from the basic functions (green boxes) to be able to include many more features

Besides the key functions, today's smart lamps and luminaires might include a broad range of smart home services such as:

- A user app to schedule events (e.g. wake-up), lighting scenes and when possible, use dimming in order to minimise energy usage;
- Recall settings for health and well-being providing the preferred light at the right time;
- Motion and daylight sensors that switch to different presets e.g., a Human Centric Lighting (HCL) preset to improve health through lighting controls that mimic the natural sunlight colour variation over the day;
- A sensor detecting when someone is in the room and switches the luminaire on;
- Temperature and humidity sensors communicating to heating, ventilation and air-conditioning units and/or thermostats;
- Boosting WiFi signal in areas where the router does not work;
- LiFi network provided for non-lighting smart services;
- Smoke detector and alarm;
- Security camera with live stream;
- Sound/speaker/music system;
- A feature that turns on the television when someone walks into the room;
- A burglar alarm that doubles the light output if a person enters the room while the lamp/luminaire is in burglar alarm mode;
- A baby monitor;
- A home intercom system receiving voice commands for control of the services; and
- Power-consumption monitoring of appliances for a desired time period.

Some of the new features include interoperability with other services (IoT), wired lighting systems (DALI), use of LiFi (see Annex II) and control from a large number of home automation systems/apps. With this development, the product has multiple primary functions and lighting may not even be the main function.

Some years ago, the uptake of smart lighting was expected to be rapid; but this has not been the case so far. The reason seems to be that there are several market barriers including cost, complexity, lack of interoperability, lack of open systems, lack of standards, lack of consistent systems, network security concerns (i.e. hacking), limited user-friendliness, and especially in the commercial sector, not being connected to wired control systems.

The big market players in smart lighting are working on overcoming these barriers through cost reduction, simplification, increased user-friendliness, plug and play solutions and so on. The research and innovation are preparing for mass use of smart lighting.

To better understand smart lighting features and the energy use associated with these features, the SSL Annex launched a study on the energy performance of smart lighting products. This study attempts to provide an evidence base for governments making policy decisions. In 2016, the first report on smart lighting was published [ref. 2]. This second report provides an update on the test method, analysis of a much larger volume of measurements and addressing the actual technical development and usage of smart and connected lighting.

The SSL Annex cooperates and coordinates its work with EDNA (the Electronic Devices and Networks Annex). The work conducted by the two IEA 4E Annexes is described below:

1. The SSL Annex works on “New features impacting LED energy consumption” (Task 7) which includes laboratory measurements of how the smart lighting features (e.g. colour tunability and dimming) affect active and standby energy consumption, efficacy and lighting quality (luminous flux, colour temperature, colour rendering, Duv etc.). More information can be found at: Smart Lighting – SSL Annex.

2. EDNA works on all different types of network-connected devices, one of which includes lighting products. EDNA is collecting indicative, non-laboratory, approximate measurements of a wide range of network-connected products, including smart LED products. EDNA aims to ensure that such devices use electricity as efficiently as possible and will help align government policies in this area. More Information can be found at: Electronic Devices & Networks – EDNA.

This report focuses on domestic smart lighting products with measurement of energy consumption (such as standby and gateway power) associated with the new features in smart lighting products. Connection to wired commercial lighting (e.g. using DALI gateways) is described later in this report.

This report offers updated guidance on smart lamps and luminaires including chapters on:

- Key terms and protocols used in communication with the smart lighting products;
- A proposed test method for measuring the performance of smart lamps and luminaires;
- Measurement results from smart lighting testing at lighting laboratories around the world including energy use of standby power, gateways, dimming, colour tuning and other features in both lamps and luminaires;
- The impact (positive and negative) on product energy consumption due to the smart service. Guidance on how to test the smart lighting products and how to minimise the additional energy consumptions is provided;
- Market potential and barriers to more widespread adoption of smart lighting; and
- Policy maker challenges and recommendations / conclusions.

2 Key terms, protocols and network architectures

2.1 Key Terms

Table 1 groups together and defines the key terms used in this report.

Table 1. Description of key terms (to a large extent original definitions) used in this report

Subject	Key Term	Description
Smartness	Smart Lighting product	A lamp/luminaire that can be controlled via a wireless signal using a smart-phone, remote control unit or other network connected device. Smart lighting products can be stand-alone products or can be part of a home automation system that may also include various appliances and an integrated energy management system along with the lamps/luminaires.
	Four categories of smart products[2]	1. **Domestic** – lighting sources offering domestic user-focused services such as dimming, colour tunability, mood setting and integrated speaker for streaming music. Typically, a smartphone app is used to control the smart products directly or via a gateway and communication between the smart products by wireless interface such as Wi-Fi, Bluetooth, Zigbee, 6LoWPAN or LiFi; 2. **Data Delivery** – connectivity enabling light sources distributed throughout a building to provide extended wireless range, security data, guiding customer movements around a shop with activation of location specific customer services, etc. through the internet, monitoring and adjustment of such systems is possible from anywhere in the world; 3. **Professional** – lighting sources offering features such as prolonging the life through active thermal control or regulation of the drive current and maintaining constant flux output. Often other protocols e.g. DALI are used. These features are typically used in the commercial sector; 4. **Economising** – lighting sources including sensors/controls in order to optimise the operation, energy and financial savings. This category of smart products includes smart street lighting that dims when there is no traffic detected on the road.
Communication	User interface	The communication device through which a user controls smart LED products, 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 shift to use of protocols with lower bandwidth and lower energy consumption. A gateway is typically housed in a separate enclosure supplied by mains power, but it can also be contained within one of the lamps/ luminaires. In the case where the lamp/luminaire is communicated with directly by Bluetooth (provided by smart phones) or WiFi (provided by a router), there is no gateway (same network all the way).
	Lamp link	Wireless communications network used as an interface to the lamps/luminaires and between the lamps/luminaires.
	Architecture	The type of architecture combining the other communication elements described.

[2] Generally, the products include more and more services that might be a mix of features from more than one of the above four smart product categories.

Subject	Key Term	Description
	Protocol	A wireless network communication protocol facilitates the transmission of data between components of a smart lighting system. Section 2.2 provides an overview of the most common wireless protocols.
Power consumption	ON_{light}	Mode where the smart lighting product is producing light in a default state without any dimming. The energy consumption for this mode is defined by the power consumption for the declared luminous flux and by the amount of time during which the product is turned ON. 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.
	ON_{others}	ON modes for some smart lighting products including integrated extra services such as camera, music, or WiFi extension. Many of these extra services are difficult or impossible to switch OFF and are thus always ON.
	STANDBY	The **Illumination-alone Standby mode** is when the lighting product is connected to a supply voltage with the illumination function off[3] but the smart lighting product continues to use energy to be ready to receive the next wireless communication from an integrated activation sensor or the user interface. In this mode the smart lighting product is not connected to the external network. The **Network Standby mode** where the lighting equipment is connected to a supply voltage with the illumination function off, while capable of being activated internal as described above or by a trigger from the external network.
Efficacy	Overall Efficacy	This efficacy metric takes into consideration the energy consumed in light ON state plus in STANDBY mode. The overall period has at least to be one day, but the accuracy improves with longer periods such as a week or a full year with the detailed specification of the known or assumed ON hours. $$Overall\ Efficacy = \frac{(Luminous\ flux \times Time_{ON})}{(Power_{ON} \times Time_{ON}) + (Power_{STANDBY} \times Time_{STANDBY})}$$ This metric is thus a characteristic of the product and its use where the Overall Efficacy can be calculated for any duration of ON time.
	Relative Overall Efficacy	When the Overall Efficacy is divided by the efficacy for the light ON mode, the Relative Overall Efficacy is calculated as shown below: $$Relative\ Overall\ Efficacy = \frac{Overall\ Efficacy}{Efficacy_{ON}}$$ $$= \frac{Time_{ON}}{Time_{ON} + \left(\frac{Power_{STANDBY}}{Power_{ON}} \times Time_{STANDBY}\right)}$$

Chapter 3 describes the recommended test method and laboratory measurements in detail. This description uses the key term "**default setting**" which is the manufacturer's factory setting when a smart lighting product is placed on the market as a new product.

[3] For some products, it can only be achieved by dimmed to zero visible light output from the user interface

2.2 Wireless Communication Protocols

Table 2 provides an overview of the most common wireless network communication protocols used in smart lighting. Part 2.3 describes the application of communication protocols in network architectures.

Table 2. Wireless Communication Protocols

		Protocol					
Characteristics		**WiFi**	**LiFi**	**Bluetooth**	**Zigbee**	**Z-wave**	**6LoWPAN**
Communication Media		Radio	High-frequency LED light Modulation (at a speed the human eye can't detect)	Short-wave-length UHF Radio 2.4 – 2485 GHz	Radio	sub-gigahertz frequency Radio around 900 MHz	Internet Low power Wire-less Personal Area Networks
Network	***Star***	X	X	X			
	Mesh				X	X	X
Data Rate (speed)	***High***	X	X	X			
	Low				X	X	X
Operating Range Distance	***Long***	X	X				
	Short			X	X	X	X
Power Consumption	***High***	X	X				
	Medium			X			
	Low			X	X	X	X
Reference/Standard		IEEE 802.11	IEEE 802.11	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.15.4	IEEE 802.15.4

Protocol associations and more details:

WiFi: Wi-Fi Alliance www.wi-fi.org. The most commonly used wireless communication protocol.

LiFi: Light Communication Association www.lightcommunications.org. There are few LiFi products at the market and none are tested by the Annex. Many believes it will become a "game changer" due to the high rate up to 10 Gb/s by connectivity enabling smart lighting products distributed throughout a premise.

Bluetooth: Bluetooth SIG www.bluetooth.org. More than 36,000 members.

Zigbee: ZigBee Alliance https://zigbeealliance.org. More than 450 members.

Z-wave: Z-wave Alliance https://z-wavealliance.org. More than 375 members. Designed for battery-operated devices and low-latency transmission of small data packets with rates up to 100 Kbit/s.

6LoWPAN: IETF https://www.ietf.org/. 6LoWPAN is the name of a concluded working group in the internet area of IETF. 6LoWPAN is an acronym of IPv6 (IP = Internet Protocol) over Low power Wireless Personal Area Networks.

2.3 Network Architectures

Four smart lighting network architectures were identified and are described below:

- Type A with a smartphone user interface using WiFi network access that connects to a **separate gateway** which transfers the communication **from WiFi to** another wireless communication protocol, e.g., **Zigbee, Z-wave or 6LoWPAN**, used to connect to the lamps/luminaires and between the lamps/luminaires.
- Type B with smartphone user interface and **all network** communication done **by** either **Bluetooth or WiFi**.
- Type C which is similar to Type A except for the separate gateway is replaced by a **lamp/luminaire with included gateway** that transfers the communication to the other lamps/luminaires.
- Type D with **a remote-control** user interface and a **proprietary star- or mesh-based network protocol** as both user and lamp link.

Illustrations of the four network architectures are shown in figure 2.

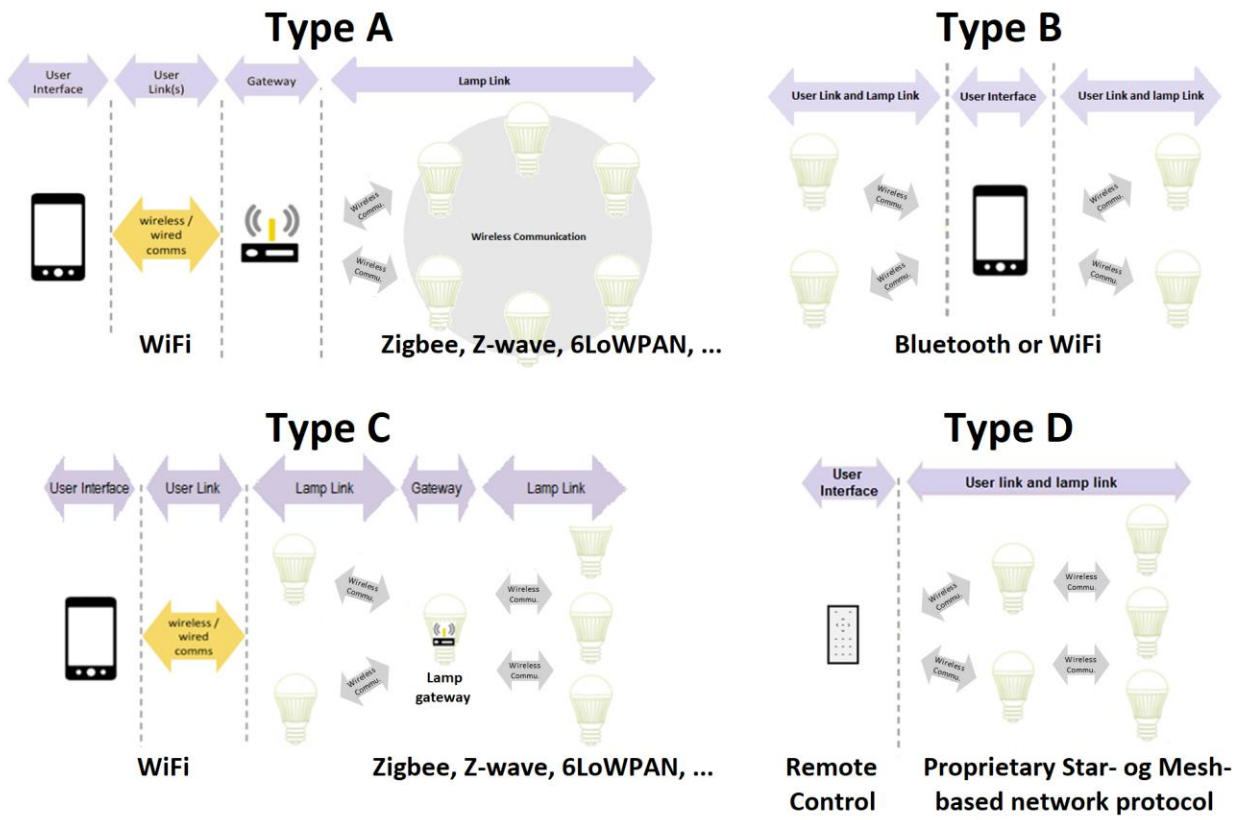

Figure 2. Four Smart Lighting Network Architectures

3 Test Method for Smart Lamp/Luminaire Testing

This chapter outlines 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 *blue text in italics* provides optional additional steps and/or practical notes for the person conducting the test. This test method was developed by the IEA 4E SSL Annex with reference to the following international test standards:

- CIE S 025/E:2015 Test Method for LED Lamps, LED Luminaires and LED Modules
- IEC 63103 Ed. 1.0 en:2020 Lighting equipment - non-active mode power measurement

3.1 Product Information

The information listed in Table 3 should be recorded for each of the models under test.

Table 3. Product information to record

Subject	Description	Information to Record	Notes
Product and purchase	Identity	• Manufacturer • Model • EAN (lamp or luminaire) • Product web link	
	Technical ID	• Cap/base • Shape • Size	
	Purchase information	• Date • Price • Currency	
Smartness	Product features	• Dimmable • Colour tunability • White tunability • Mood settings • Audio speaker • Web cam • WiFi extender • Auto ON/OFF based on IR occupancy sensor • Auto ON/OFF based on ultrasound movement sensor • Auto ON/OFF based on sound sensor • App version • Timer • Scheduler • Circadian scheduler • Home and away • Synchronize to music/games/movies • Wake-Up function • Go to sleep function • Auto adjust light output and colour appearance (K) • Memory of recent used colour • Other	Is the smart lighting product part of a dedicated home automation system? (yes/no)

Subject	Description	Information to Record	Notes
Gateway		• Model • EAN • Rated ON power • Max number of lamps/luminaires per gateway	Architectures including gateway
Communication	User interface	3. Wireless network structure with interface via: o smart-phone app, o remote control unit or o other medium	Included with the product in the package? (yes/no)
	Protocol	4. Protocol for user link o WiFi, Bluetooth 5. Protocol for lamp link o Star network (WiFi, Bluetooth) o Mesh network (Zigbee, Z-wave, WeMo, 6LoPLAN etc.)	Did you face start-up or communica-tion protocol challenges?
Electrical Supply (rated)	Power supply	6. Rated voltage range 7. Rated frequency range	
Power Consumption (rated)	ON mode	8. Rated value on packaging/data sheet/ product	If possible, CCT for rated value
	STANDBY mode	9. Rated value on packaging/data sheet/ product	Note if not provided
Light Output (rated)	Luminous flux	10. Rated value(s) on packaging/data sheet/product	If possible, CCT for rated value(s)
Colour quality (rated)	CCT (Three options depending on the smartness of the product)	11. One rated value on packaging/data sheet/product 12. A few rated values on packaging/data sheet/product 13. CCT range/interval	If max CCT > 6500 K, does the product comply with blue hazard testing requirements?
	RGB(W) lighting product	14. LEDs incorporated into the smart lighting product	Does the product incorporate red, green and blue LEDs which enable the user to select any light colour? (yes/no)
	CRI	15. Rated value on packaging/data sheet/product	Is CRI provided for a range of CCTs?
	Pre-set scenes	16. Descriptions of the pre-set scenes offered	

3.2 Product Sampling

A sample size of 1–3 lamps/luminaires 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 models as possible. With a sample size of 1–3 units per model, the test results should be interpreted as indicative measurements.

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 10 units of each product model selected for market surveillance testing.

3.3 Laboratory and Environmental Conditions

The laboratory and environmental conditions shall be as specified in CIE S 025/E:2015, Section 4.2 "Laboratory and Environmental Conditions", unless other requirements are stated in another referenced standard within subsequent sections of this document.

3.4 Configuration for Test

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

Optional testing: Where it is possible to reset the product (to factory default settings) by a dedicated button or a switching sequence, the product should be retested after a reset.

***Caution**: Before changing out-of-the-box settings, confirm that it is possible to return to them as some products do not provide the ability to return to factory default settings.*

3.5 Operation

The lamps/luminaires shall be operated by the user interface *e.g.* a smartphone, remote control or other device. It must be ensured that the products are working as intended, including functions such as dimming, and colour tuning controlled by the user interface. A user link (e.g. WiFi or Bluetooth network) is required in order to operate the product.

3.6 Electrical Test Conditions

The test voltage and electrical power supply shall be as stated in CIE S 025/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.

3.7 Stabilisation

The stabilisation shall be done as stated in CIE S 025/E:2015, Section 4.1.1 "LED lamps and LED luminaires". Similarly, to all other lamp types, the smart product needs to be stable before test measurements are conducted. The product shall be stabilised for at least 30 minutes in the state in which it is to be measured. The smart product is considered 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-minute period. If the smart lamp exhibits large fluctuations and the stabilization conditions are not met within 45 minutes of operation (150 minutes 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 minutes 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/luminaire. See also IEC 63103 Ed. 1.0 en:2020 Lighting equipment - Non-active mode power measurement.

Note: To observe the variation and stabilisation of power consumption, measurements shall be taken at a high sampling rate (e.g. every few seconds) with calculation of a total period average. For smart lighting products, the stabilisation period for the ON mode might be longer as they 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).

3.8 Measurement Period

It is recommended that the measurement for all lamp/luminaire modes is done in one session to avoid the lamp/luminaire cooling and to minimise the stabilisation periods every time the luminous flux or CCT is changed. Stabilisation of voltage and luminous flux should be confirmed (as per clause 3.7 criterion) after each change in operating configuration.

3.9 Electrical Measurement Equipment

All electrical measurements are to be conducted with measurement equipment (namely power meter, voltmeter, current meter) that satisfies the requirements of CIE S 025/E:2015, Section 4.3.2 "Electrical Measurements", unless more stringent requirements are stated in another referenced standard within subsequent sections of this document.

3.10 STANDBY Power Measurements

After operating the lamp/luminaire in the default (out of the box) ON for 30 minutes, set the lamp/luminaire to STANDBY and, after ensuring the lamp is stabilised (see section 4.4), measure the STANDBY power consumption in accordance with IEC 63103 – Lighting Equipment – Non-active power mode measurement.

Standby power shall be measured for the following:

- The lamp/luminaire alone (without network connection)
- The lamp/luminaire with network cable to the router (and network connection established)
- For lamps/luminaires which include additional features (e.g., daylight sensor, move-ment sensor, voice control, music, etc.) which cannot be switched OFF, the power consumed by these features is included in the measured STANDBY power. Then, the technician must try to estimate the power consumed by these features and deduct it from the measured result to determine the lamp/luminaire standby power alone.

3.11 Gateway Power Measurements

Gateways are only utilised for communication architecture Type A (see explanation in Annex III). Measure the power consumption of the gateway while at least one lamp/luminaire is connected[4]. There might be a little difference in the power consumption if the network cable is connected to the router or not, so measurements for both these stages are included. Connection conditions during measurement are to be reported.

3.12 ON Measurements

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

If the product includes extra services such as music from the product, WiFi extender and security camera and the product design is such that these services are ON all the time, then the power consumption measurements shall include these extra services. If these services are to be switched ON by the consumer and/or are only ON for a limited time, they shall be switched OFF for the measurement of ON_{light}. When the lighting is off, the ON_{other} should be measured where possible separately for each additional service.

3.12.1 Lamps/luminaires with Adjustable Colour Temperature

For many smart lamps/luminaires, the default (factory) setting is not specified on the package or elsewhere. First, it is therefore very important to determine the default CCT setting. Hereafter, the lowest and highest CCT achievable by the product shall be found to determine which nominal CCTs the product can provide. In general, the testing shall include the default factory setting, lowest and highest CCTs achievable by the product plus the nominal CCTs 2700 K, 4000 K and 5000 K and for dimmable products be conducted at maximum light output.

Table 4. 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 CCT adjustable smart lamp/luminaire models, five methods of setting the CCT can be found in the market today. The five setting types are listed below along with a recommended practical procedure for selecting 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.

[4] Simple measurement of power consumption regardless of how many more lamps/luminaires the gateway supports appears to be sufficient as test [15] has shown constant gateway power with variating number of connected lamps/luminaires.

- 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 towards the centre from the red region and the highest CCT is towards the centre from the deep blue region (see Figure 3).

Figure 3. Indicative regions for setting the minimum (red ellipse) and maximum (blue ellipse) CCT

- CCT value (K) or the chromaticity coordinates can be entered: Enter the values.

3.12.2 Dimmable Smart Lamps/Luminaires

For those lamps/luminaires with adjustable light output (i.e. dimmable) testing shall be conducted with measurements at four dimming levels: 100 %, 75 %, 50 % and 25 % for the default factory setting CCT. Preferably, dimming should be based on the percentage reduction of light output or power consumption relative to the maximum light output (100%). (If the last method is used, it should be reported).

For dimmable smart lamp/luminaire models, three methods of setting the dimmed levels can be found in the market today (listed below along with a recommended practical procedure for selecting 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 smart lighting product at a set position with a calibrated illuminance meter and slide with best possible accuracy to achieve the relative illuminance.

3.12.3 Measurements

Table 5 provides a matrix of the combinations of CCT and dimming level to test (note: it will be less if the lamp/luminaire is only able to provide one of these features). The default setting is the factory setting. Compared to the first status report (ref. 2), the recommended mandatory measurements in Table 5 are fewer, in order to reduce the measurement costs. For each combination of CCT and light output level, the following should be measured after stabilisation (see section 3.7):

- Lamp/luminaire power and the total spectral radiant flux;
- Luminous flux;
- CCT;
- Duv for the nominal CCTs; and
- CRI.

Table 5. ON Measurements (combinations of CCTs and lighting output) to be included in testing

		CCT						
		Default	Min	2700K	4000K	5000K	6500K	Max
Light Output[1]	100 %	M	M	M	M	M	O	M
	75 %	M	O	O	O	O	O	O
	50 %	M	O	O	O	O	O	O
	25 %	M	O	O	O	O	O	O
	Min	Only measure the luminous flux and the lamp/luminaire power						

M= Mandatory   O = Optional

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

If voice control is available, it might be preferable for the selection of a specific CCT because selection methods included in most apps often provide a small rendition of the CIE colour space map on a smart-phone screen, which when navigated with a relatively large fingertip is normally not very precise. The same often appears for selecting a dimming level by an app.

Extra optional testing could be:

- *Measurements for all nominal CCTs (see Table 3).*
- *Measurements for CCTs that are of interest to the requesting party.*
- *Measurements for other settings.*
- *Measurement of CCT (e.g. every minute) from cold start until lamp/luminaire has stabilised and eventually for restart of lamp/luminaire after cooling.*
- *Test repeatability of selection of CCT under various control scenarios including approaching selected CCT from higher and lower CCTs.*

Note: If the smart product is able to provide a CCT > 6500 K (some products offer up to 14000 K), then the government regulators are advised to consider mandating photo-biological hazard testing, criteria for sales in the consumer market plus warning about the health hazard risk for blue light and required provision of a link to additional information/guidelines.

3.13 Tool to calculate the Overall Efficacy

Measuring $P_{STANDBY}$ and P_{ON} makes it possible to calculate the overall efficacy for any ON-time durations using the formula specified in part 2.1.

Alternatively, Figure 4 can be used in the typical situations where $P_{STANDBY}/P_{ON}$ is ≤ 25 %. The procedure for using this tool includes the following steps:

1. Measure $P_{STANDBY}$ and P_{ON}.
2. Calculate $P_{STANDBY}/P_{ON}$.
3. Find the relative overall efficacy in Figure 4 based on the $P_{STANDBY}/P_{ON}$ calculation and ON-time duration per day (hours ON).
4. Multiply with the ON efficacy.

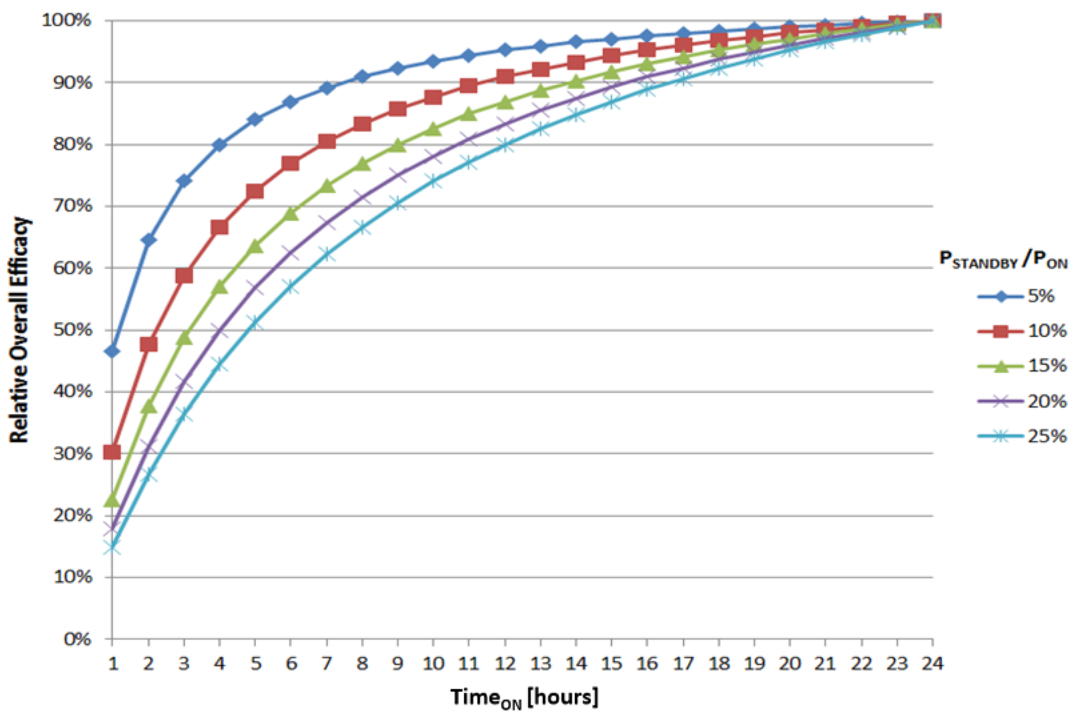

Figure 4. Relative overall efficacy for $P_{STANDBY}/P_{ON}$ being 5, 10, 15, 20 or 25 %

3.14 Measurements Related to Health Aspects

Health aspect measurements are not directly related to smart lighting, but as the IEA 4E SSL Annex considers health measurements in other tasks, it is included in these test method measurements:

1. Blue Light Hazard (RG);
2. P_{st}^{LM} Short term flicker index; and
3. SVM Stroboscopic effect Visibility Measure.

3.15 Data collection tool and database

The SSL Annex has developed an Excel tool for collection of measurements with worksheets for control and overview of products tested, covering all the possible smart features for these lamps and luminaires.

Figure 5 below shows the Excel tool data collection template for one smart lighting product. Please note that due to the high number of necessary columns in the data collection tool template, it has been broken into three sections so it can be viewed more easily in this format.

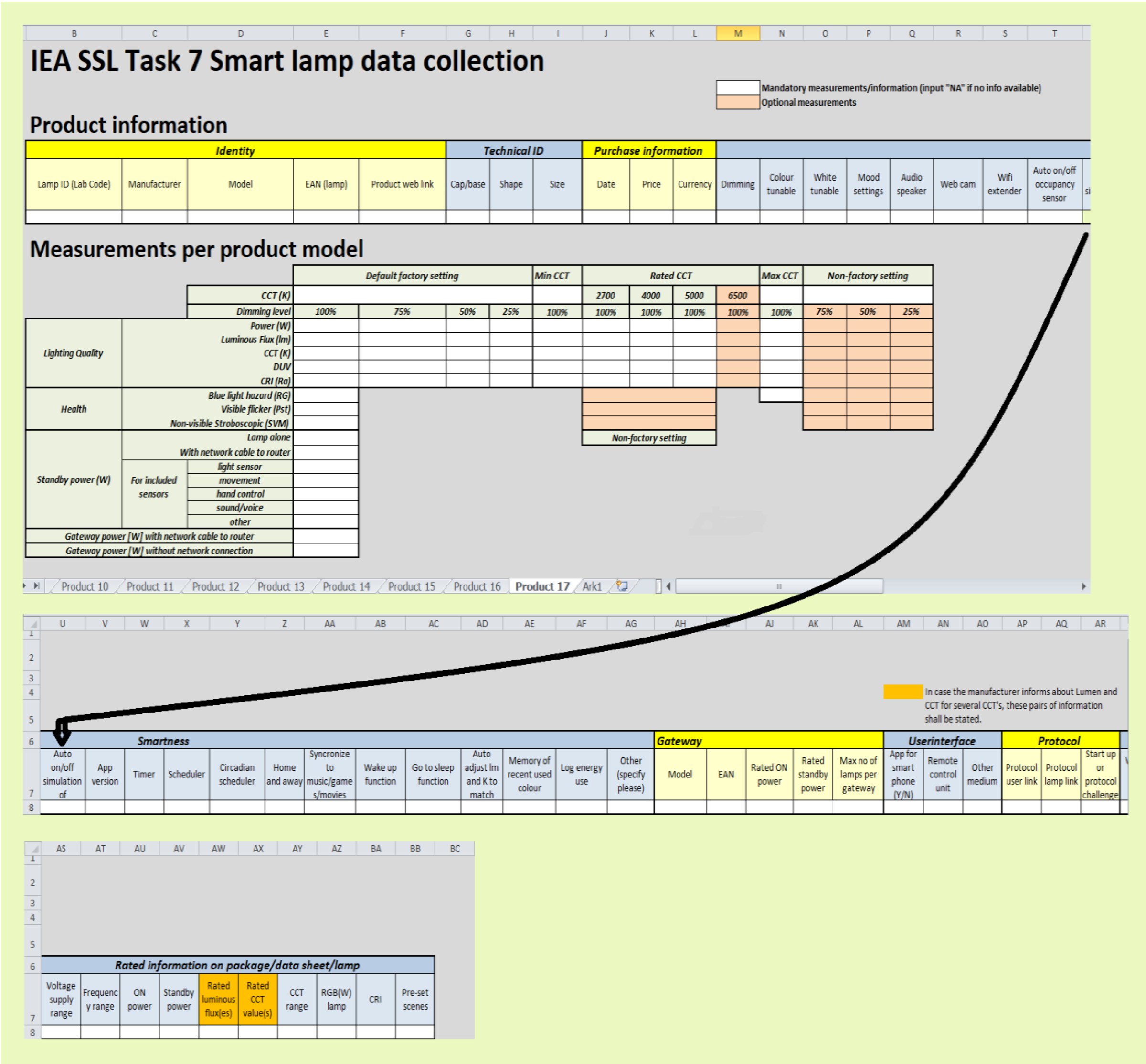

Figure 5. Data collected for a smart lighting product

4 Results from Indicative Smart Lighting Product Testing

4.1 Overview of Tested Products

Between 2015 and 2020, the SSL Annex compiled test data on 236 smart lighting products (lamps and luminaires) that were purchased and tested in Annex member country lighting laboratories. Of these products, 34 lamps (from 2015) were also included in the first report (ref. 2), while the results of 202 smart lamps/luminaires are new in this report, and their performance data has not been presented. Table 6 provides a summary of the products tested and the characteristics that were measured in the different laboratories. The products tested include all the major brands/models at the market in Australia, Europe, and North America.

Table 6. Testing of Smart Lighting Products in SSL Annex Member Country Lighting Laboratories

Year	Country[1]	Number of Products Tested			Characteristics Measured for the Products Tested				
		Lamps	Luminaires	Total	Standby	Efficacy	Lamp link info	Dimming	Different CCT
2015	Report 1	34	0	34	34	34	34		
2016	Canada	15	0	15	15	15	14		
2017	France	16	0	16	16	6	15	6	9
2018	Canada	29	0	29	29	29	28		11
2018	USA	77	0	77	77	75	77		
2017-19	Denmark	7	1	8	8	8	8	8	6
2019	Australia	4	0	4	4	4	4	4	3
2019	South Korea	3	0	3	3	3	3		3
2020		7	6	13	13	13	13	6	6
2018-20	Sweden	13	3	16	16	16	15	13	7
2020	Denmark	12	5	17	17	17	17	17	13
2020	Australia	0	4	4	4	4	4	4	4
2015-20	**TOTAL**	**217**	**19**	**236**	**236**	**224**	**231**	**57**	**62**

[1] Australia, Canada and Denmark appear twice because the data was delivered separately in different years

The laboratories that have conducted this testing and shared their data are listed below:

- CSTB, Photonics Lab, Grenoble, France
- DTU, Photonics lab, Roskilde, Denmark
- Eric Page & Associates, USA
- KILT Lab, South Korea
- Korea Testing Certification, Lighting Centre, South Korea
- LEDlab, Australia
- Steve Jenkins & Associates, Australia
- Swedish Energy Agency Testlab, Sweden
- Westboro Photonics, Ottawa, Canada
- Woburn Lab, Massachusetts, USA

4.2 Lower Efficacy for Smart Lamps/Luminaires

Figure 6 shows the measured efficacy for 224 smart lighting products (including 205 lamps and 19 luminaires) purchased and tested between 2015 and 2020. The data is presented in chronological order along the X-axis, from left (2015) to right (2020). As seen for normal LED lighting sources, the efficacy is increasing in the period but there is a large variation in efficacy. The average efficacy of all 224 smart products tested was 73 lm/W (average of the highest efficacy of each product), including 74 lm/W for the lamps and 68 lm/W for the luminaires.

For comparison, looking at normal (i.e., not smart) LED products in the large US ENERGY STAR database from 2015-2019, the average efficacy was about ten lumens per watt higher at 83 lm/W. That value is influenced by the fact that the ENERGY STAR database only consists of lighting products with efficacy ≥ 80 lm/W, whereas of the smart lighting products tested, 43% (97 of 224) had efficacy values ≥ 80 lm/W. The average efficacy of this sub-group is 89 lm/W, which is comparable with the non-smart lighting products in the ENERGY STAR database.

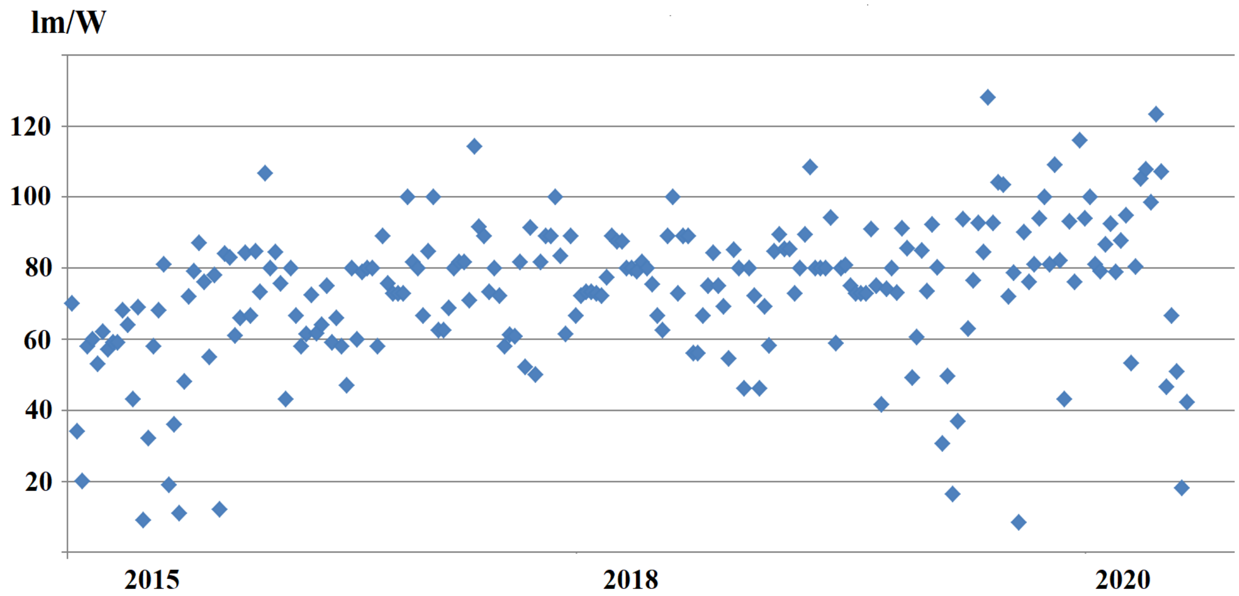

Figure 6. Measured efficacy for 224 smart lighting products, the SSL Annex database, 2015 - 2020

4.3 Gateway Power Consumption

Smart lighting architecture Type C (see Annex III) includes a gateway housed in a separate enclosure from the smart lighting products and is connected to mains power. A typical gateway can support up to 50 lamps/luminaires.

Figure 7 shows the measured power consumption of 23 gateways for different products. Except for two outliers (small manufacturers) with higher power consumption, the power consumption varies between 1.0 and 1.7 W. The average load for all 23 models tested was 1.5 W.

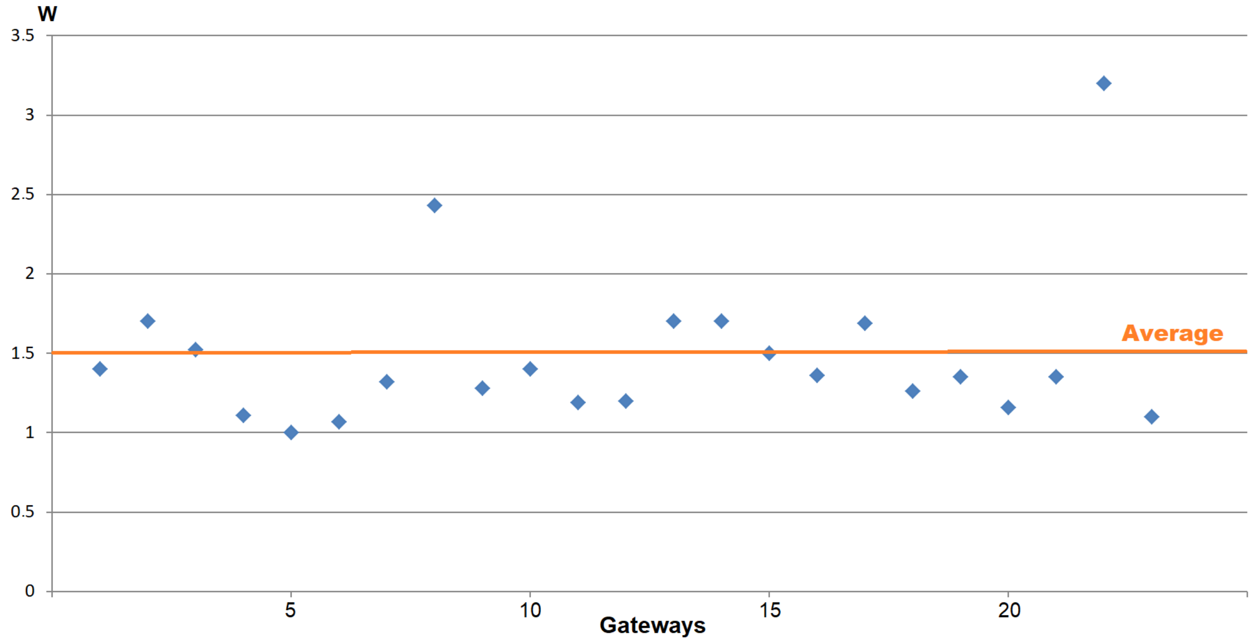

Figure 7. Gateway power consumption (W) measured for 23 gateways for different products

The gateway is typically always ON and with an average power of 1.5 W, the annual average energy consumption is 13.1 kWh/year. The energy consumption per lamp/luminaire depends on how many lamps/luminaires are served by the gateway.

Table 7 shows some examples of the annual consumption per lamp for a typical smart 9W lamp providing 806 lm with standby power 0.33W (average for the tested products with standby power ≤ 0.5 W as shown in part 4.4.), and gateway power 1.5W and assumed ON-time of 700 h/year (i.e., 2 hours per day) and resulting standby power duration of 8060 h/year.

Table 7. Examples of annual energy consumption for a common 9W smart lamp with gateway

Smart lamps per building	Annual Energy for ON	Annual Energy in Standby	Annual Energy for Gateway	Total Energy per lamp
Units	*(kWh/yr)*	*(kWh/yr)*	*(kWh/yr)*	*(kWh/yr)*
1 lamp	6.3	2.7	13.1	22.1
3 lamps	18.9	8.0	13.1	13.3
5 lamps	31.5	13.3	13.1	11.6
10 lamps	63.0	26.6	13.1	10.3
20 lamps	126.0	53.2	13.1	9.6

Figure 8 shows that the gateways' share of the annual energy consumption per lamp can be very significant going from 59% when the gateway is supporting only 1 lamp to gradually less as the number of lamps supported increases e.g. 33% when the gateway supports 3 lamps, 23% when supporting 5 lamps, 13% when supporting 10 lamps and 7% of total power use when the gateway supports 20 lamps.

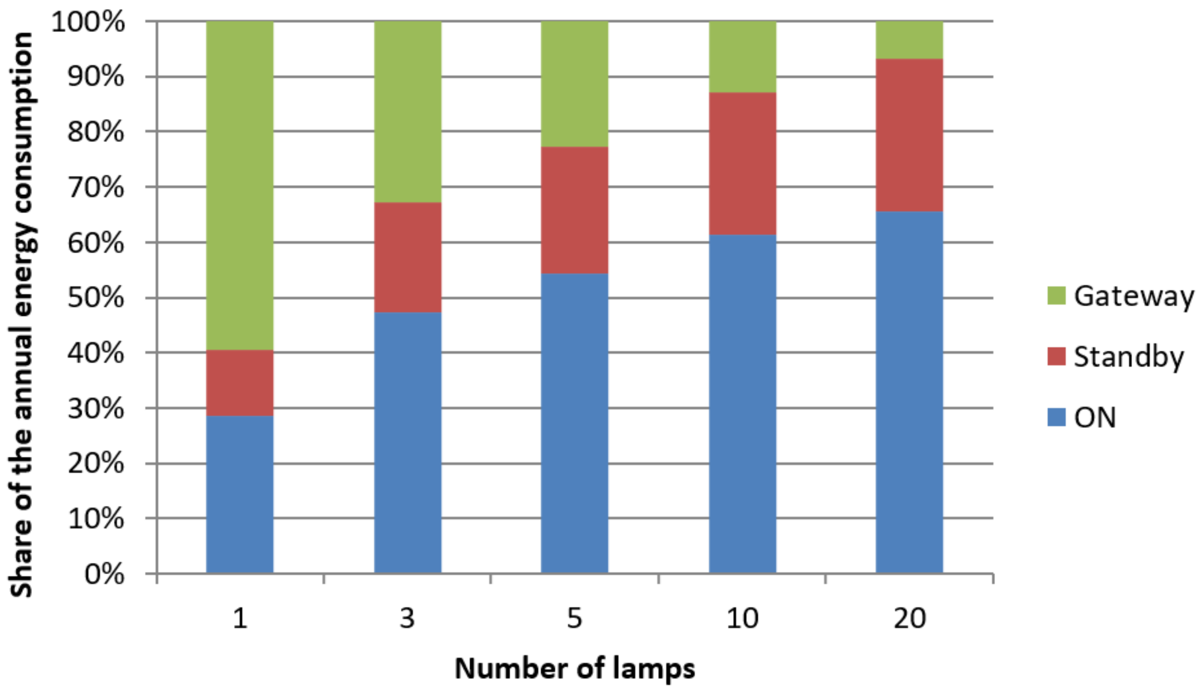

Figure 8. Example of the gateway lighting consumption share of the total lamp consumption

4.4 Standby Power Consumption

The first IEA 4E SSL Annex smart lighting report [ref. 2] presented the test results of 34 smart lighting products and found a substantial standby power variation from a low of 0.08 W to a high of 2.71 W and with an average power consumption of 0.50 W.

This report includes 236 smart lamps/luminaires coming from 67 different manufacturers. These products were tested during the period of 2015-2020. Figure 9 presents their standby power in chronological order. The standby power varies between 0.08 W and 3.5 W.

Table 8 shows the calculated values of average standby power for the different segments of the 236 smart lighting products:

- 0.45 W for lamps;
- 0.63 W for luminaires;
- 0.51 W for both lamps and luminaires (slightly higher than that reported in SSL Annex, 2016 [ref. 2], the median is 0.39 W;
- 28% of the products have standby power > 0.5 W with an average of 0.94 W;
- 72% of the products have standby power ≤ 0.5 W with an average of 0.33 W; and
- 6% of the products have standby power ≤ 0.2 W with an average of 0.16 W.

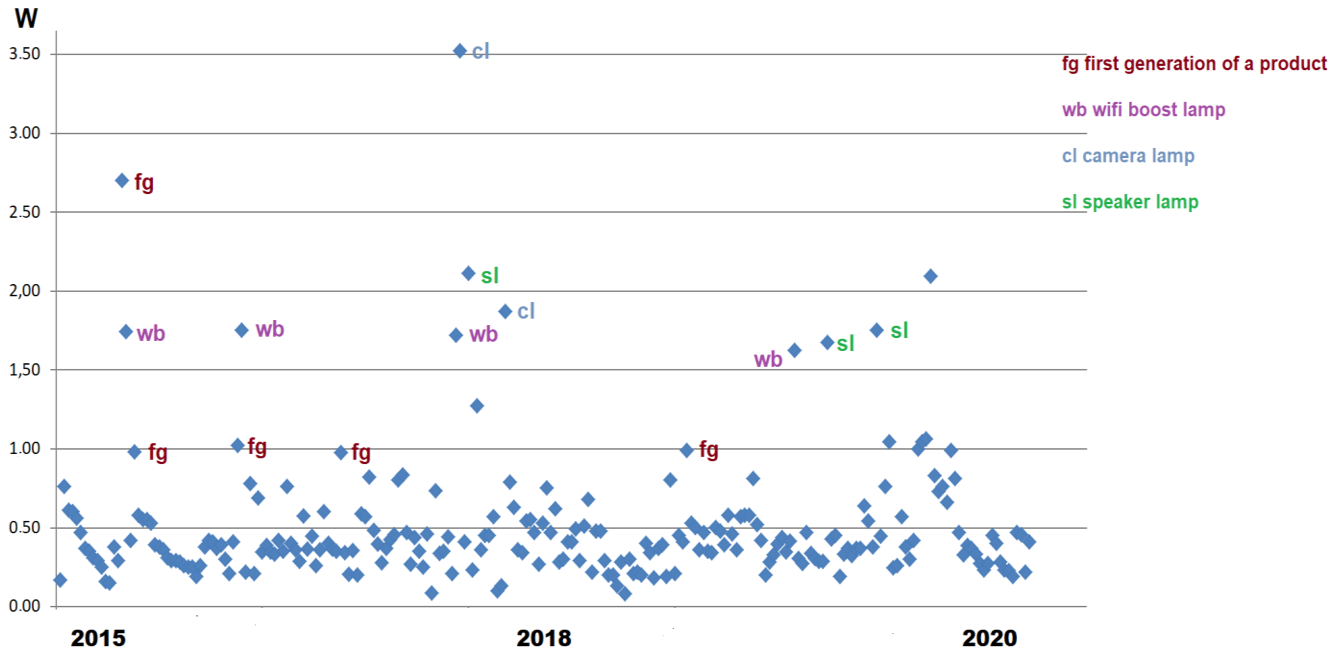

Figure 9. Standby power consumption for 236 smart lighting products

Table 8. Average standby power for different segments of smart lighting products

Segment due to the size of the standby power (W)	Number of products	Average standby power (W)	
		lamps	Luminaires
All	217	0.45	
All	19		0.63
All	236	0.51 (median 0.39)	
> 0.5	67 (28%)	0.94	
≤ 0.5	169 (72%)	0.33	
≤ 0.3	64 (27%)	0.23	
≤ 0.2	15 (6%)	0.16	

Some smart products were initially found to have a very high standby power, while subsequent testing of that product (i.e. a later versions of the model) during the period 2015 – 2020 found a notable reduction of the standby power. Figure 9 presents five examples (marked with ”fg") of smart lighting product measurements, where the manufacturers reduced the standby power in updated versions of those same smart lighting products.

Figure 10 includes two examples of a model redesign leading to a lower standby power level:

- Product 1 with standby power was 2.7 W in 2015 and 0.2 – 0.8 W in 2018-19 (probably due to different OEM suppliers around the world using different electronic components in production).
- Product 2 with standby power 1 W in 2015 and 0.3-0.6 W in 2016-18 except one product at 1 W which is may have been a first-generation product sold late.

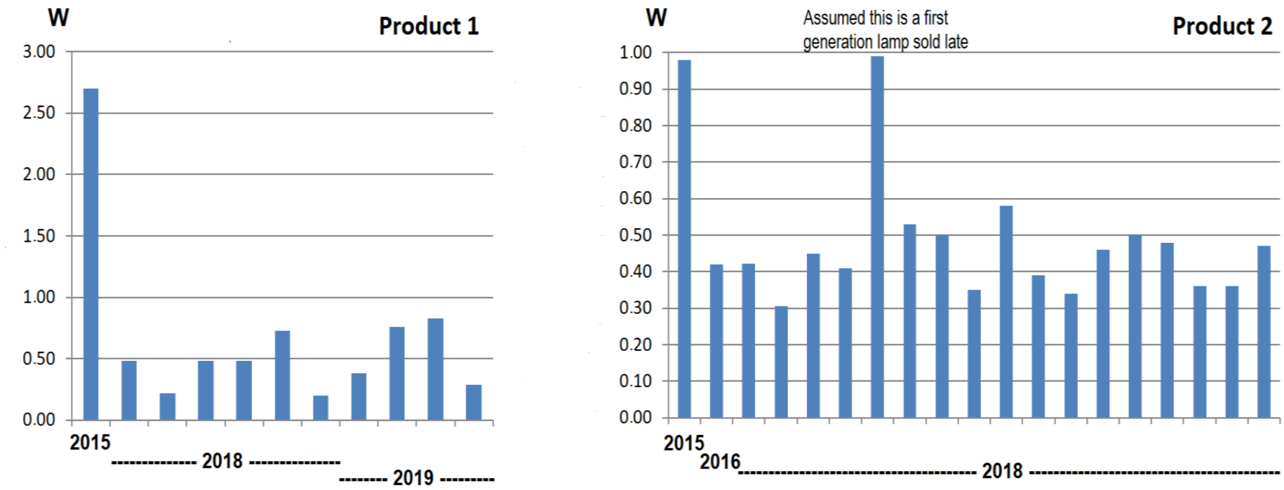

Figure 10. Two smart lighting products where redesign led to significantly lower standby power

For many products, the standby power measured in one country can be different from the value measured for the same product in a different country. The reason for these variations could be the use of different OEM suppliers or production lines for different batches of the product, where different electronic components are used in the drivers.

Besides the high first-generation standby power values, a major reason for products with standby power > 1 W (see Figure 9) appears to be that these products include extra non-lighting features such as cameras, WiFi boosters or speakers which are typically always ON.

It is recommended that manufacturers make it possible to switch the non-lighting features ON and OFF so that end-users can disable features they may no longer want or need, and thereby save energy during the lifetime of the smart lighting product. This also makes it possible for laboratories to analyse the energy consumption consumed by non-lighting features.

Finally, Figure 9 presents 2020 test results of eight smart lighting products that have standby power consumption of approximately 1 watt. These smart products were purchased in Korea where the government has not yet set maximum standby power regulations. California, on the other hand, does have a regulation limiting standby to 0.2 watts, and their market offers consumers hundreds of smart lamps and luminaires with standby less than 0.2 watts. The contrast between the standby power consumption of smart products sold clearly demonstrates the effectiveness of energy-efficiency policies (see part 5.2).

4.5 Average Standby Power for the different types of Lamp Links

The majority of the smart lamps and luminaires tested use one of the following two communication architectures (see part 2.3):

- Type A with combined use of WiFi and Zigbee protocols including a gateway to convert the communication between these protocols; and
- Type B configuration in two versions, using Bluetooth or WiFi.

Lately, many of the products that started with architecture Type A have become available in a new version where they include both Type A plus Type B using Bluetooth. The testing includes few of these new products so statistically they could not be handled as a separate group.

Table 9. Average standby power consumption for the three major Communication Architectures

Communication Architecture Type	Average Standby Power	Number of Products
Units	*(Watts)*	
Type A (WiFi - gateway - Zigbee)	0.36	79 (43%)
Type B using Bluetooth	0.39	60 (32%)
Type B using WiFi	0.55	46 (25%)
Totals		185

Table 9 shows that the average standby power of communication architecture Type B using Bluetooth is close to the average standby power of Type A. Considering that Type A architecture also includes an energy consumption for a gateway (see section 4.3), then the architecture Type B using Bluetooth has the lowest consumption. Bluetooth also has the benefit of easier connection without a gateway, and this protocol also supports loudspeaker inclusion in the lamp/luminaire. This might be the reason why many manufacturers using communication Type A, lately, have added Type B with Bluetooth as an alternative.

Comparing Type B using Bluetooth and WiFi, the standby power consumption is higher for WiFi (see Table 9). WiFi however provides high-speed internet access within a range of 50 m (for indoor situations) while Bluetooth is not designed for internet access but communication within a range of 10 m. For smart lighting products used in the home, the trend appears to be that communication architecture Type B using Bluetooth is the preferred option.

For the commercial sector, the situation is more complex with more extensive requirements regarding the number of cell nodes, distances, and bandwidth. Wired communication has already been installed in many places, including lighting controls (e.g. using the protocol DALI). In any case, smart wireless lighting systems have the potential to connect to a range of other services e.g., data collection, data analysis, security, fire safety, climate control and navigation in a building. This interoperability between wired and wireless control is supported by the DALI Alliance, who has specified gateways between DALI and Bluetooth as well as between DALI and Zigbee-based products [ref. 21].

4.6 Product Performance when Dimming

Residential smart lighting products are typically controlled by either a remote unit, a touch lamp/luminaire function with selection between a few dimming steps or by selecting the dimming level freely in an app on the smart-phone screen.

The proposed measurement method (see section 3.12.3) includes mandatory measurement of the dimming performance for the CCT factory default setting. Figure 11 shows the default CCT setting for 58 lighting products where dimming is tested. The most common default setting is 2700 K and the second most common default is 3000 K.

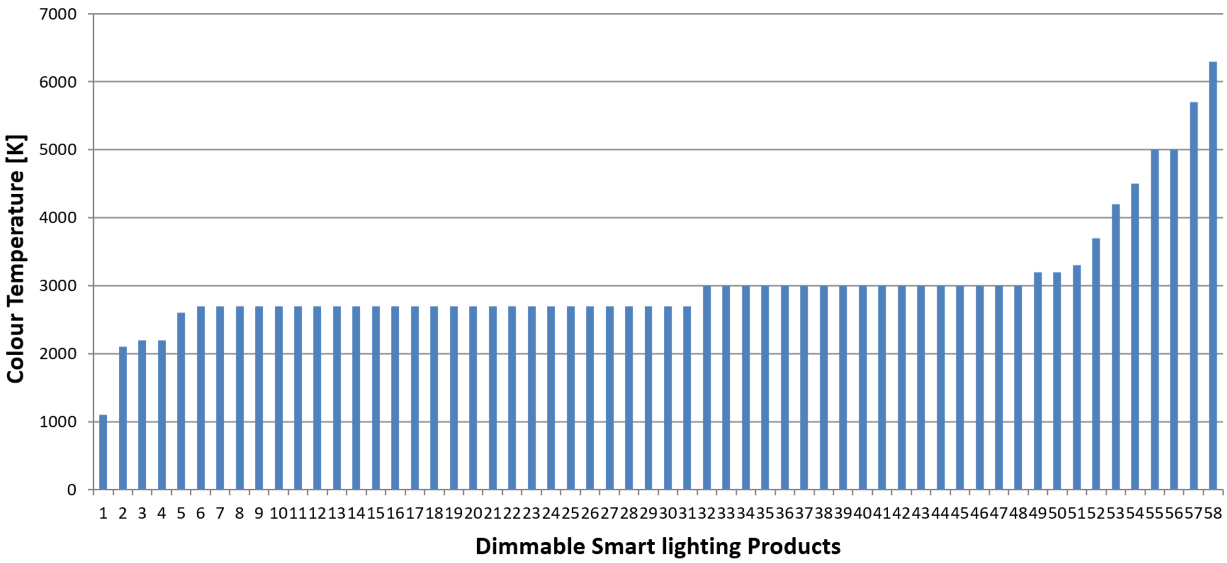

Figure 11. CCT default (factory) setting for smart lamps/luminaires where dimming is tested

For 25 of the 58 lighting products, dimming performance was only tested in the default setting. For the majority of the remaining 33 products, the dimming performance was tested at four to five CCT of the nominal values 2200, 2700, 4000, 5000 and 6500 K.

General analysis of the test results for product performance when dimmed reveals:

1. The variation in relative efficacy (relative to the efficacy without dimming for a particular CCT) when dimming is similar for different colour temperatures, except for a few models which had deviations at a single CCT. For this reason, the revised measurement method (see section 3.12.3) only includes mandatory testing of dimming performance for the factory default setting of CCT.
2. The CCT was found to be consistent while dimming the lamps/luminaires.
3. For the majority of smart lamp/luminaires tested, the CRI was consistent while dimming and remained above 80. However, there were a few products which did have a small insignificant change in CRI while dimming.

By examining the graphs of the variation in the efficacy when dimming, the products can be separated into five general dimming groups (DG). Figure 12 shows the average relative efficacy when dimmed for each of the five dimming groups, whereby:

- DG-1 includes 5 products which achieved higher efficacy while dimming, especially at the 75% and 50% light output levels, where the efficacy increased by about 22%;
- DG-2 includes 18 products where the efficacy was relatively constant at 100, 75 and 50% light output, but then decreased by about 6% at 25% light output;
- DG-3 includes 21 products which experienced increasing reductions in efficacy as the product was dimmed, with approximately a 3%, 8% and 24% decrease in efficacy at 75%, 50% and 25% light output, respectively;
- DG-4 includes 9 products which exhibited higher losses in efficacy as the product was dimmed, having a 15%, 29% and 57% decrease in efficacy at 75%, 50% and 25% light output, respectively; and
- DG-5 includes 5 products which had the largest reduction in efficacy of the sample tested, experiencing a 40%, 50% and 74% decrease in efficacy at 75%, 50% and 25% light output, respectively.

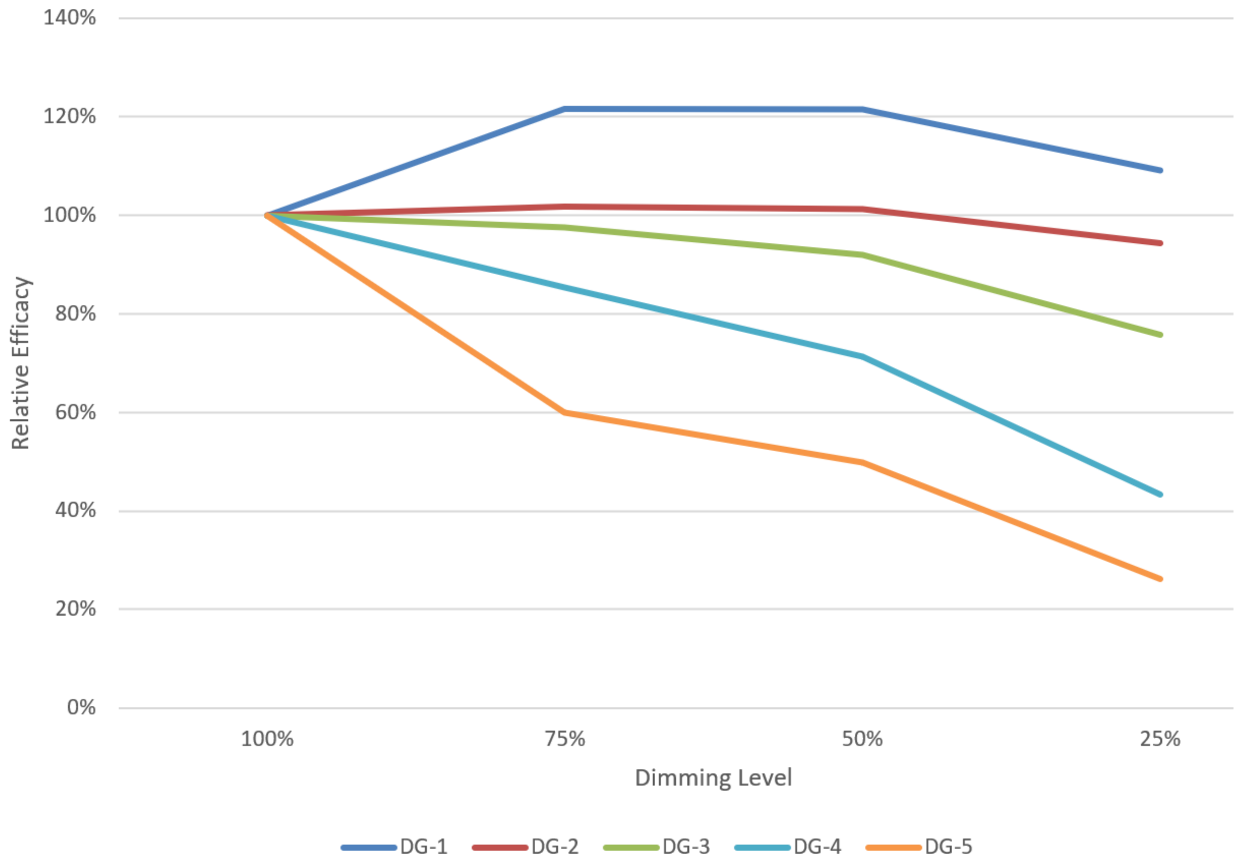

Figure 12. Changes in efficacy of 58 smart products, clustered in five Dimming Groups

DG-1 makes up less than 10% of the products. It is not a problem for customers that the efficacy is higher when they dim as this increases the estimated energy savings by dimming.

DG-2 makes up 31% of the products with dimming. These products consistently hold the rated efficacy for all dimming levels (except for a small decrease for 25% light output). With these products, the customers are able to capture energy savings by dimming.

DG-3 makes up 36% of the products with dimming. The efficacy is only 3% and 8% lower for 75% and 50% less light output respectively, so the slightly lower efficacy is not significant for these products.

DG-4 and DG-5 together makes up 24% of the products. For these products the efficacy is significantly lower for all dimming levels and most importantly, customers will fail to retain energy savings and will not be aware of the power lost during dimming.

For dimmable smart products, it is recommended to require that the manufacturers provide rated information about luminous flux, power, and efficacy for the dimming levels: 75%, 50% and 25% light output for the CCT factory default setting**.**

4.7 Product Performance at Different Colour Temperatures

For colour-tuneable lamps/luminaires, manufacturers typically state the maximum luminous flux as the rated luminous flux, but the customer may not be informed at which CCT this occurs, and how much lower the luminous flux is at other CCTs.

Figure 13 provides the light output across a range of CCT values for two different smart lamps. Example 1 produces 810 lumens at 5000K CCT and example 2 provides over 1000 lumens at 3500K. For both lamps, the measured luminous flux is much lower (up to 40% less) at other CCT values.

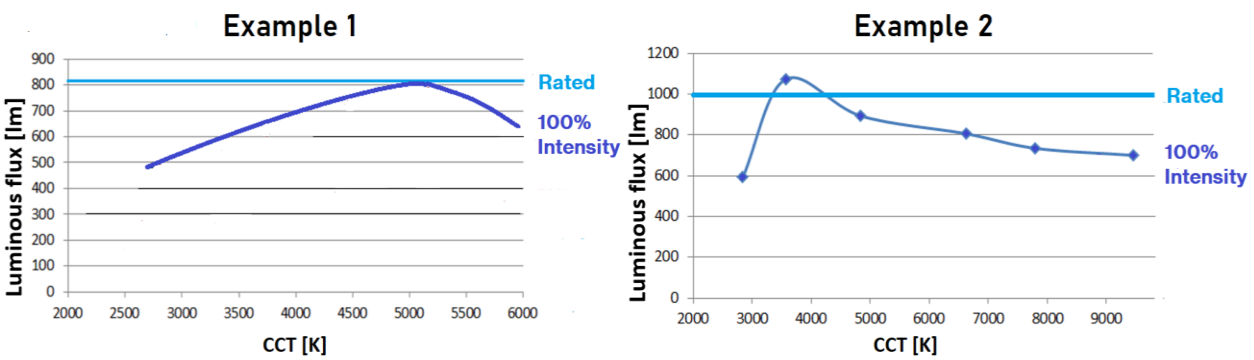

Figure 13. Two examples of measured total luminous flux as a function of CCT

Recently the IEA 4E SSL Annex identified a smart lamp with package information displaying the luminous flux at two CCTs (see figure 14). Unfortunately, only one rated power value is displayed, which is possibly for the setting having the highest luminous flux value.

Figure 14. Packaging for a smart lamp giving information on luminous flux at two different CCTs

Figure 15 shows the measured variation in luminous flux related to maximum luminous flux for each of the 22 smart lighting products.

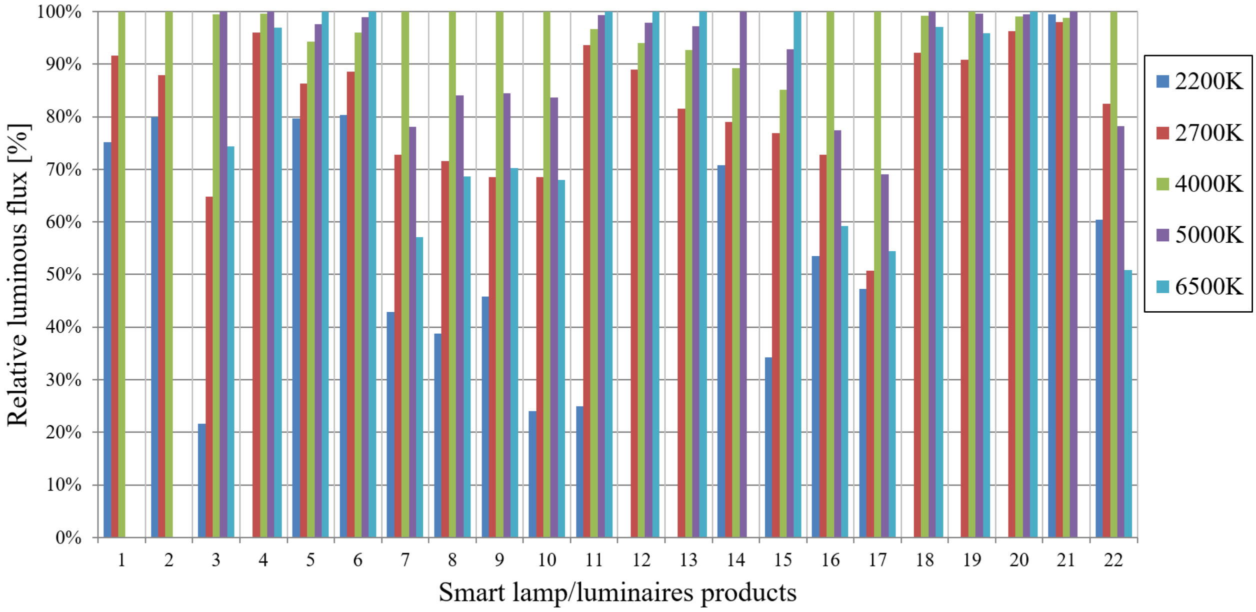

Figure 15. Measured luminous flux for five CCT settings relative to the maximum luminous flux

The products exhibit a wide degree of variability, comparing for example model #3 in Figure 15 which has only 20% relative luminous flux at 2200 K, to example model #21 which has nearly constant luminous flux across all CCTs.

The maximum luminous flux is at 4000 K for most lamps/luminaires. The minimum luminous flux is at 2200 K in nearly all cases where this CCT is selectable.

The largest variations in light output with CCT illustrated in Figure 15 are expected to be an issue for the consumer as they are typically neither informed about the CCT for the rated luminous flux nor the variation in light output with change of CCT. The consumer may assume the rated light output is claimed for all CCTs and therefore have a negative experience if their new smart lamp/luminaire provides 900 lm at 4000 K but only 500 lm at 2700 K. The consumer would notice this difference and may conclude that the product doesn't provide good lighting.

The preferred solution would be for the manufacturer to provide the luminous flux, power and efficacy for all nominal CCT's within the selectable range. It is recommended to require the manufacturers at least provide information on the package and online about the luminous flux, power and efficacy for two CCT's, a warm colour (e.g., 2700 K) and a cool colour (e.g., 4000 or 5000 K) and note in the product report online those CCT values or ranges where the luminous flux is less than 70% of the maximum luminous flux.

Figure 16 shows the measured luminous efficacy (without dimming) as a function of the measured CCT. It should be noted that the set CCT was often not exactly at target nominal CCT value due to limited user friendliness in selection of the CCT (as described in chapter 6). For these lamps and luminaires, three types of variation were observed as the CCT was adjusted:

1) Increasing efficacy with increasing CCT (shown with solid lines) with 20-50% variation;
2) Highest efficacy at 4000 K (shown with dashed lines) with 20-50% variation; and
3) Almost no variation in the efficacy (shown with dotted lines) corresponding to the products in figure 15 with almost no variation in the luminous flux.

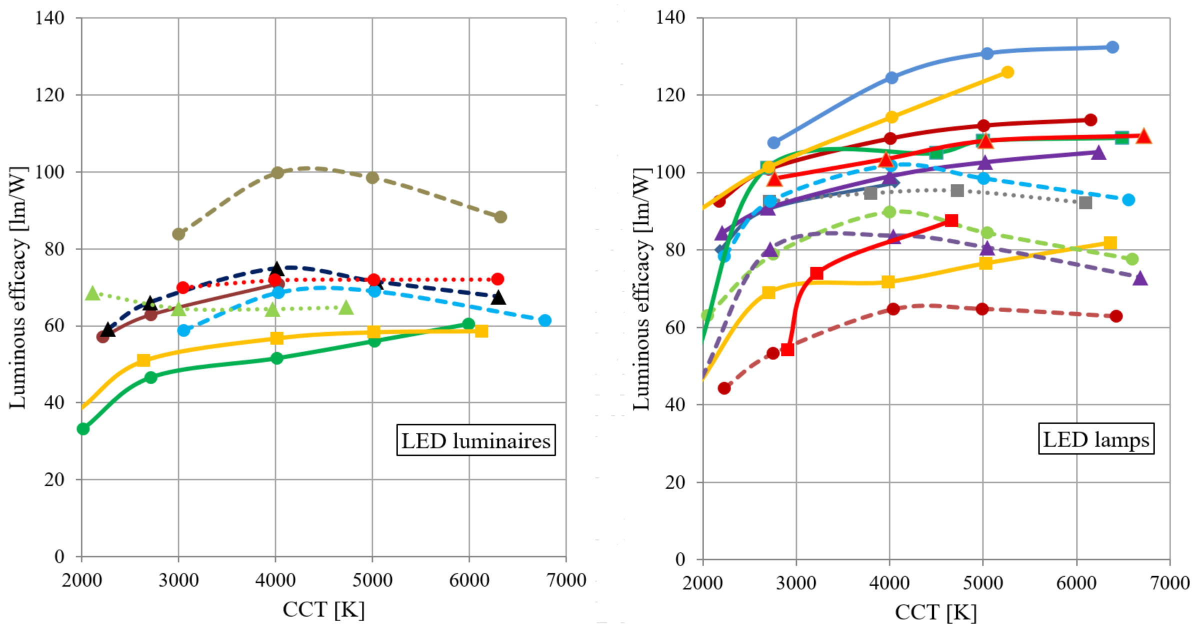

Figure 16. Efficacy as a function of CCT for 14 lamps and 8 luminaires

5 Large Energy Saving Potential by Standby Power Regulation

5.1 Huge Reduction of Standby Power by using the Wake-Up Radio Concept

A way to obtain substantial reduction of the standby power was described by IEEE a few years ago and was developed for IoT connected devices on a battery[5] powered system (see Figure 19). In this concept, a low power radio receiver (Wake-Up Radio) is added to the device (in this case, a smart lighting product).

Essentially, the low power radio receiver is the only thing that stays "awake" but only for 2 milliseconds out of every 100 milliseconds (0.1 second). Use of this concept reduces the average power by a factor 50. In case of a product with a standby power of 0.2 W, the addition of the Wake-Up Radio system therefore reduces the time-averaged standby power to 0.004 W (4 mW). For a standby power of 0.5 W, a similar time-averaged reduction is to 0.01 W.

The low power radio receiver "listens" for a special signal that communicates when information that is sent to the lighting product and in that case, the low power radio receiver wakes up the main radio (which typically uses WiFi or Bluetooth) and then data exchange starts – all without any delay or reduction in the quality of the user experience.

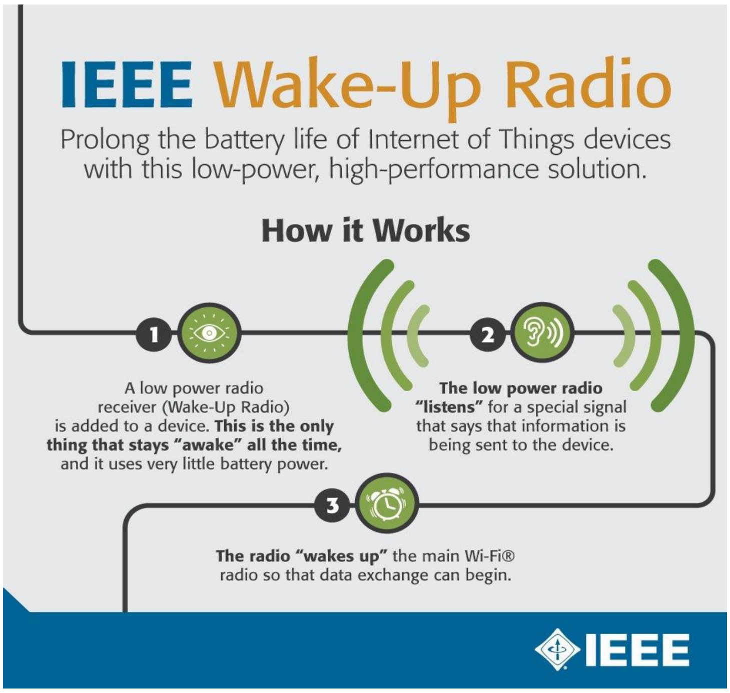

Figure 17. IEEE Wake-Up Radio Concept

5 http://innovationatwork.ieee.org/wp-content/uploads/2017/11/WUR-Preview-with-links.pdf

5.2 Much lower Standby Power for the same products in California

In the California Code of Regulations (CCR) Title-20, certain smart LED lamps/luminaires that meet the definition of "state-regulated LED lamps" in section 1602(K) were required to have a standby power consumption of 0.2 Watts or less from 1 July 2019.

The California Energy Commission's (CEC) MAEDBS database had 558 models[6] of state-regulated smart LED products registered with Bluetooth, Zigbee, WiFi, or other type of communications protocol that is reported to meet the ≤ 0.2 W requirement.

Figure 18 presents the standby power for all 558 certified products, sorted by increasing reported standby power use.

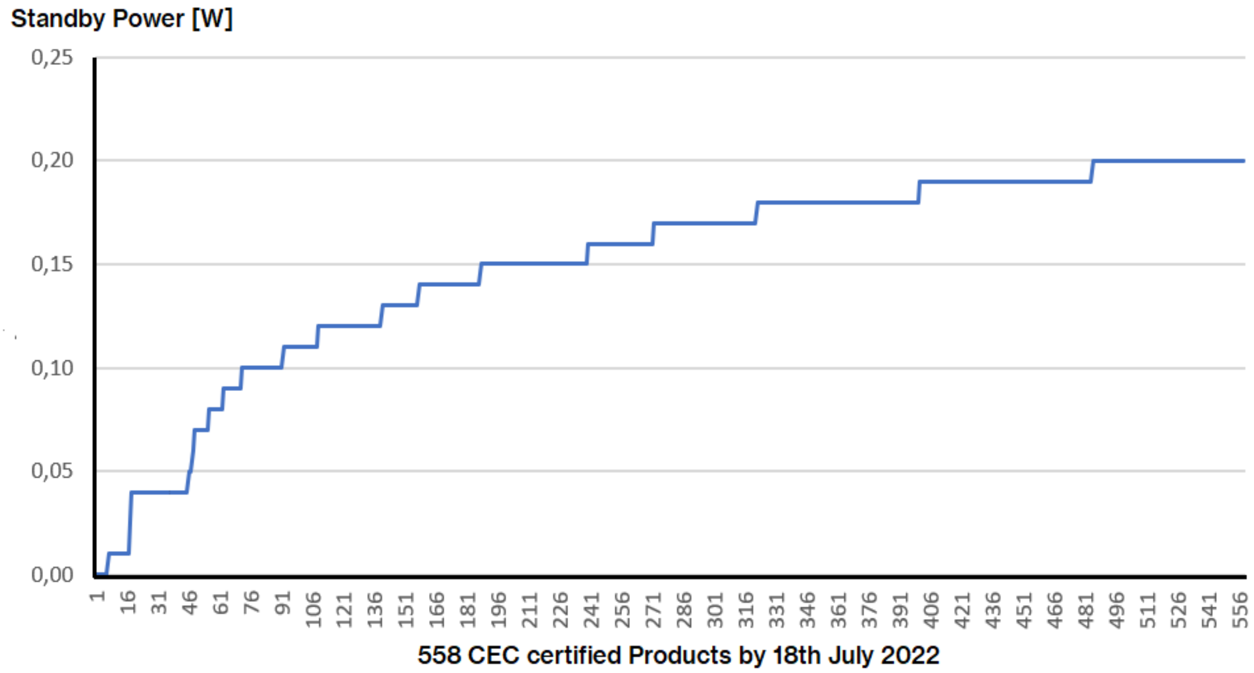

Figure 18. Standby power ≤ 0.2 W for 558 certified smart lighting products, CEC California

Several lighting manufacturers have confirmed they use the Wake-Up Radio concept (see section 5.1). It is presumed this technology is the major reason for practically all the major manufacturers' products for sale in California complying with the Californian standby regulation of maximum 0.2 W.

5.3 Low Smart Lighting Standby Power in North America

Outside of the California market with its ambitious regulation limiting standby power in smart lighting products to ≤ 0.2 W, the ENERGY STAR programme in USA and Canada certifies energy-

[6] MAEDBS Advanced Search (ca.gov) accessed July 2022.

efficient products including lamps/luminaires. Their requirements for LED lighting set a limit on standby power of maximum 0.5 W.

The ENERGY STAR database (accessed August 2022) includes 504 models of smart LED products with standby power consumption using Bluetooth, Zigbee, WiFi, or another type of protocol. Figure 19 shows the standby power for the 504 products in the ENERGY STAR database plotted in increasing order.

A total of 410 (81%) of the products in the ENERGY STAR database fulfil the California standby power limit ≤ 0.2 W requirement. This fact indicates that in the broader USA market, there are a significant and substantial co-benefits in terms of the smart lighting products placed on the market due to the standby requirements set in California (see part 5.2). The products included in the ENERGY STAR data base are, to a large extent, products that are also sold elsewhere in the world.

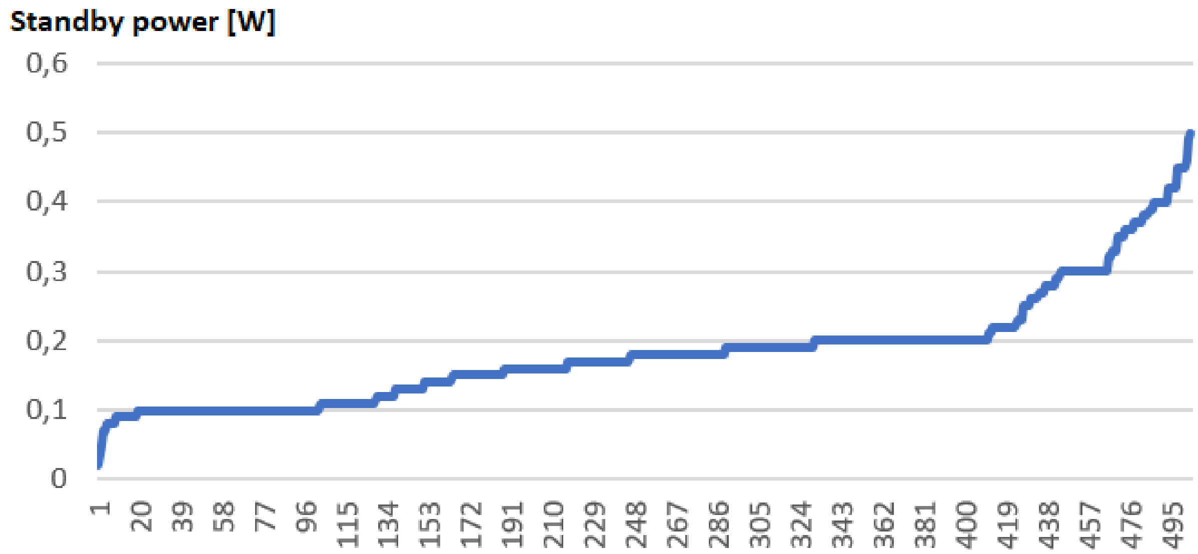

Figure 19. Standby power for 504 different ENERGY STAR certified smart lamps (USA)[7]

5.4 When is Standby Power Consumption Significant?

The magnitude of standby power consumption where it is no longer an issue can be evaluated by the overall efficacy metric (see part 2.1).

The first IEA 4E SSL Annex smart lighting report [ref. 2] found that smart lighting products with high standby losses (e.g., 1W, 2W, 3W) would have an overall efficacy that was often the same as an incandescent or halogen lamp.

Since the first report was published, the European Union adopted new regulations (December 2019) which took effect on 1 September 2021 limiting the standby power to a maximum of 0.5 W. In 2019, California set a limit of maximum 0.2 W on standby power. Australia and New

[7] ENERGY STAR Certified Light Bulbs | EPA ENERGY STAR accessed on 3 August 2022.

Zealand have proposed to implement a limit aligned with that of the EU at 0.5 W in 2024. Compared to 6 years ago, the efficacy of standard LED lamps as well as smart lamps are higher.

Revisiting the calculation from the SSL Annex's first report, the following table presents a calculation for standby power limits of 0.5 W and 0.2 W (currently in place in the EU and California, respectively) plus possible future limits of 0.1 W and 0.01 W. These four different standby power levels are evaluated for two smart lamps that provide 360 lm and 806 lm respectively. Assuming both of these lamps have an on-mode efficacy of 120 lm/W, the overall efficacy for the typical domestic ON times of 1 and 2 hours per day are calculated and presented in Table 10.

Table 10. Overall efficacy depending on the size of the standby power, two examples

Smart Lamp Examples	Standby power (watts)	Overall efficacy for $Time_{ON}$ 1 hour (lm/W)	2 hours (lm/W)
360 lm 3 Watts 120 lm/W	0.5	25	42
	0.2	47	69
	0.1	68	88
	0.01	111	116
806 lm 6.7 Watts 120 lm/W	0.5	44	66
	0.2	71	90
	0.1	89	103
	0.01	116	118

Table 10 shows:

1. With standby power of 0.5 W and an ON time of 1 - 2 hours/day, the overall efficacy is 45 – 79% below the rated efficacy;
2. With standby power of 0.2 W and ON time of 1 - 2 hours/day, the overall efficacy is 25 – 61% below the rated efficacy;
3. With standby power of 0.1 W and ON time of 1 - 2 hours/day, the overall efficacy is 14 – 43% below the rated efficacy;
4. With standby power 0.01 W and ON time of 1 - 2 hours/day, the overall efficacy is 2 – 8% below the rated efficacy;

From these four scenarios of varying standby power and operating times, it is notable that especially with an ON time of 1 hour/day, the overall efficacy is significantly lower than the rated efficacy except in the case where the standby power is 0.01 W.

Another way of reviewing the impact of standby power limits is presented in Figure 20, where the overall efficacy is plotted for the 3 W (360 lm) smart lamp in case of four different standby power levels (0.01, 0.1, 0.2 and 0.5 W) with the ON time varying from 1 to 24 hours per day. In Figure 21, the same calculation and plot is presented for the 6.7 W (806 lm) smart lamp.

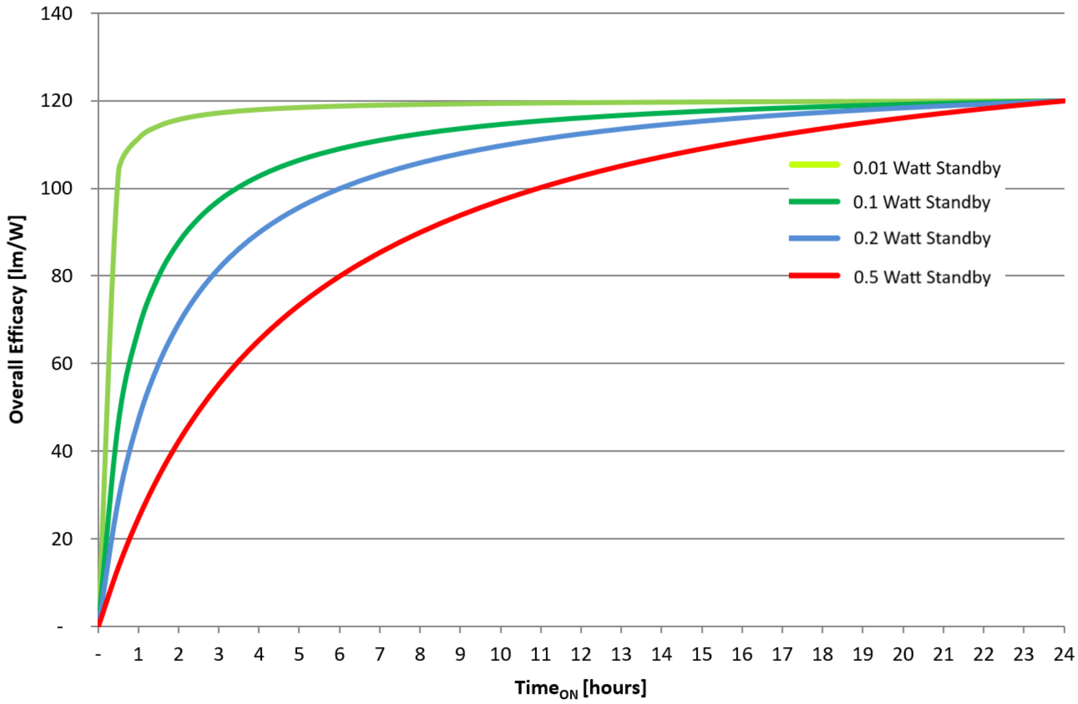

Figure 20. Overall efficacy for 3 W (360 lm) smart lamp for varying Time$_{ON}$ per day

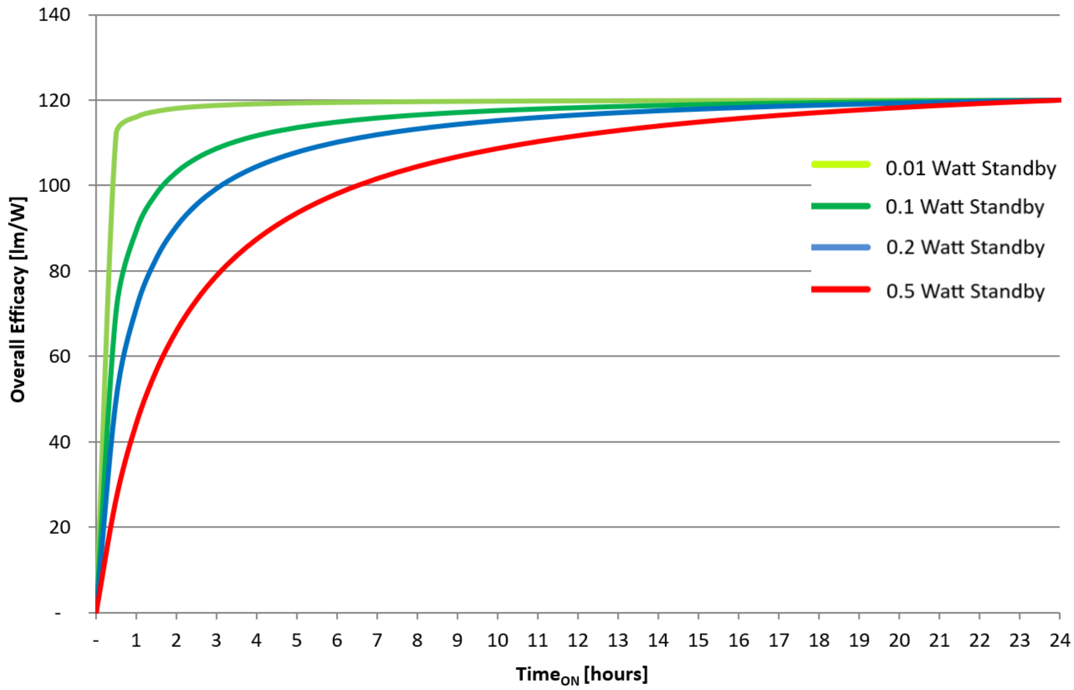

Figure 21. Overall efficacy for 6.7 W (806 lm) smart lamp for varying Time$_{ON}$ per day

Both Figures 20 and 21 show that the standby power must be around 0.01 W before the overall efficacy is close to the rated efficacy for all ON times down to 1 hour of use per day. Thus, the analysis presented in Tables 10, Figure 20 and Figure 21 show that standby power consumption is significant until it is reduced to approximately 0.01 W.

5.5 Standby energy's share of the total energy consumption

In the first IEA 4E SSL Annex smart lighting report [ref. 2], it was found that with product operation of 1 h/day, half of the yearly energy consumption consisted of standby mode consumption. In the situation where the product operation time was 2 h/day, it was found that a third of the yearly energy was consumed in standby mode.

Table 11 provides updated calculations on this analysis for two smart lamps, one providing 360 lumens and one with 806 lumens. Both lamps have the same on-mode efficacy of 120 lm/W. The influence of standby power is analysed by calculating the yearly energy consumption for operational times of 1 and 2 hours/day (the typical average usage for lamps used in the domestic sector [ref. 13]).

Table 11. Energy consumption for varying standby power for two lamps used 1 or 2 hours/day[8]

			Usage 1 hour/day				Usage 2 hours/day			
Lamp	ON (W)	Standby Power (W)	ON (kWh)	Standby Energy (kWh)	Standby Energy (%)	Total (kWh)	ON (kWh)	Standby Energy (kWh)	Standby Energy (%)	Total (kWh)
360 lm	3.0	0.50	1.10	4.20	**79%**	5.3	2.19	4.02	**65%**	6.2
		0.20		1.68	**61%**	2.8		1.61	**42%**	3.8
		0.10		0.84	**43%**	1.9		0.80	**27%**	3.0
		0.01		0.08	**7%**	1.2		0.08	**4%**	2.3
806 lm	6.7	0.50	2.45	4.20	**63%**	6.6	4.89	4.02	**45%**	8.9
		0.20		1.68	**41%**	4.1		1.61	**25%**	6.5
		0.10		0.84	**26%**	3.3		0.80	**14%**	5.7
		0.01		0.08	**3%**	2.5		0.08	**2%**	5.0

The annual energy consumption results presented in Table 11 and illustrated in Figure 22 and Figure 23 demonstrate that for the two lamps (3.0 Watts and 6.7 Watts) operated for **1 hour per day:**

- If the standby power is 0.5 watts, the standby energy consumption of the two lamps is 79% and 63% of total annual energy use.
- If the standby power is 0.2 watts, the standby energy consumption of the two lamps is 61% and 41% of total annual energy use.
- If the standby power is 0.1 watts, the standby energy consumption of the two lamps is 43% and 26% of total annual energy use.
- If the standby power is 0.01 watts, the standby energy consumption of the two lamps is 7% and 3% of total annual energy use.

[8] The calculation does not include gateway consumption because it appears only for some of the lamps and because the gateway consumption per lamp depends strong on the number of lamps supplied by the gateway (see section 4.3).

The annual energy consumption results for the same two lamps if operated for **2 hours per day**:

- If the standby power is 0.5 watts, the standby energy consumption of the two lamps is 65% and 45% of total annual energy use.
- If the standby power is 0.2 watts, the standby energy consumption of the two lamps is 42% and 25% of total annual energy use.
- If the standby power is 0.1 watts, the standby energy consumption of the two lamps is 27% and 14% of total annual energy use.
- If the standby power is 0.01 watts, the standby energy consumption of the two lamps is 4% and 2% of total annual energy use.

Presenting the annual energy use for these two lamps graphically, the following figure 22 (worst case) and 23 (best case) illustrate, the analysis shows that standby power consumption doesn't become insignificant until it is reduced to around 0.01 W.

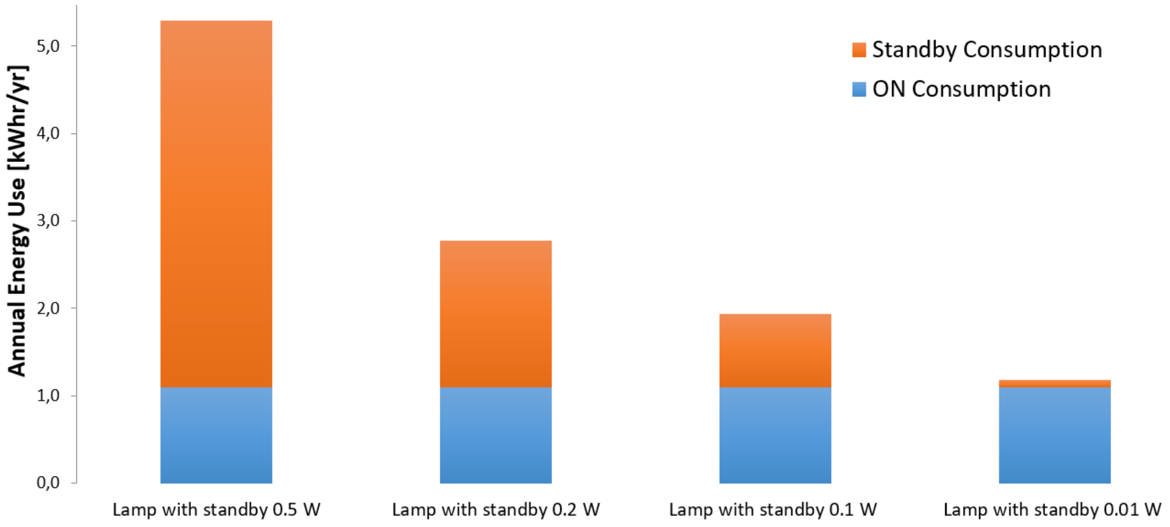

Figure 22. Annual energy consumption for 360 lm smart lamp in operation 1 hour/day

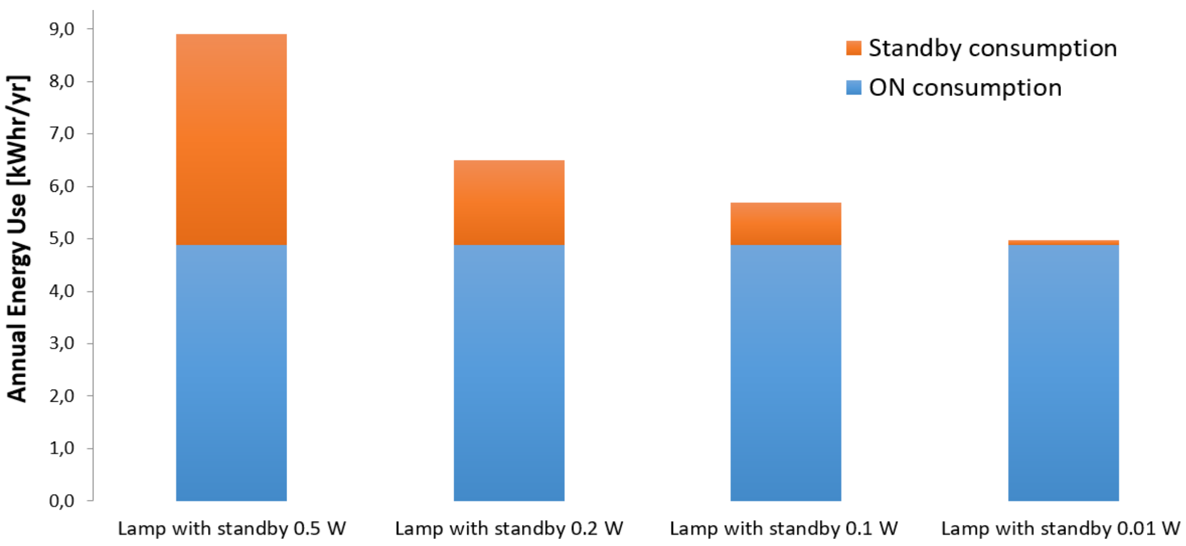

Figure 23. Annual energy consumption for 806 lm smart lamp in operation 2 hours/day

5.6 Control and reducing standby consumption for non-lighting features

Many smart lighting products include non-lighting features such as sensors, WiFi boosters, speakers, and cameras. These features are often always ON, resulting in much higher standby power. The lack of control (i.e., to activate and deactivate) of these features makes it impossible to limit their additional energy consumption.

In 2020, IEC published the standard IEC 63103 which contains definitions of non-active modes as well as a template for reporting power measurements including non-lighting functions (see Figure 24). While recognises the increasing importance of non-lighting features, the standard does not describe how to measure the standby power separately for each function. This is not easy to do as the measurement method will vary by type of non-lighting function.

It is recommended that manufacturers make it possible to switch any non-lighting features ON and OFF so that end-users can disable features they may no longer want or need. Policy regulators may consider making this recommendation mandatory as it could lower standby energy consumption. It is also recommended that manufacturers consider using the wake-up concept for these functions as shown in the previous section, even standby power levels of 0.5W, 0.2W and 0.1W will make considerable contributions to the overall lighting energy consumption.

Table 3 – Example of using the template of Table 2 for reporting measured standby power for an illumination-only luminaire with integrated presence sensor

	Non-active mode			
Function	**Function status**			
	Off	**Standby**	**Networked standby**	**On**
Illumination		X		
Sensing				X
Imaging				
Energy storage				
Powering				
High network availability				
...				
...				
Measured non-active mode power	Value		0,50	
	Unit [W]		W	
Key: greyed cells indicate non-applicability.				

Figure 24. Standard IEC 63103 Template for reporting smart lighting standby power

Making these new functions switchable (*i.e.*, ON and OFF) also makes it possible for lighting laboratories to measure and analyse the energy consumption consumed by different extra non-lighting features.

6 Market Potential and Barriers

6.1 Market Potential

In the residential sector, the market potential of smart lighting systems is large including lighting and non-lighting features as:

- ON/OFF control,
- Changing CCT,
- Dimming,
- Use of motion detection,
- Daylight sensors that can cause a room to switch to different pre-sets *e.g.*, a HCL pre-set where daylight colour temperature variation is imitated,
- Temperature and humidity sensors to control air-conditioning or thermostats,
- Boosting of WiFi signal,
- Smoke alarm,
- Security camera,
- Sound/speaker/music system,
- Burglar alarm initiating overhead light,
- Baby monitor and
- Monitoring of energy consumption plus other things.

In the commercial sector, the market for smart lighting in shopping centres, supermarkets, museums and exhibition halls is very large. In these places, consumers and visitors will interact with products and displays, and smart lights can enhance that experience, activating visual and aural information to navigate a building, find products or learn about exhibited items.

In the home, the operation might be just a few hours per day as people are out working, going to sports/fitness places and other free time activities.

In contrast to this, the daily operating hours of commercial buildings are typically longer so control features can be used to realise large energy savings by turning OFF or modifying lights not used.

Five years ago, smart lighting was predicted to experience a mass uptake in the forms of sales of smart lighting systems as well as entire integrated smart home services packages. The uptake has not been as fast as projected; however, the market is still growing.

In a recent interview, Signify (formerly Philips Lighting) estimated that approximately 5% of the domestic customers use smart lighting [ref. 15]. However, Signify also report that the COVID 19 pandemic - with people staying a lot of time at home – gave a boost to smart lighting sales in the domestic sector.

6.2 Barriers and the Way Forward

The market development of smart lighting has not been as fast as expected probably due to a mix of barriers described below. In this section, efforts to remove the barriers are discussed, in order that energy-efficient, feature-rich, smart lighting can continue to grow in market share and enhance the user experience.

- **First cost**
  Some of the initial smart lighting products coming from the large manufacturers were costly. Recently, many smaller or less known manufacturers have started to sell smart lighting products in supermarkets and other consumer outlets for much more competitive prices. The **general price level for smart lighting is therefore decreasing**. The trend is similar to what we have already seen for normal (non-smart) LED lamps and luminaires.

- **Too difficult to get started**
  In many cases it is **too difficult to download the app and install** smart lighting products even for experienced test laboratory technical staff. Manufacturers need to work on making products easier to setup and more intuitive.

- **Too complex**
  Use of different **protocols,** communication **architectures** (see part 2.3) possibly with a gateway is too complex for some end-users. There is a general trend towards using the **Bluetooth** protocol **(**see the reasons in part 4.4**)**. Several manufacturers (all large manufacturers) have added Bluetooth in their products as an alternative to the use of WiFi combined with Zigbee by use of a gateway. When lighting products include speakers/music, Bluetooth appears to be used in all products no matter if they use other protocols for the lighting. In the future, Bluetooth might become the **de facto standard** communication protocol for smart lighting in the **domestic** sector.

- **Lack of sufficient user-friendliness**
  Many apps appear to be too difficult to use and navigate. Several manufacturers are working on improving their respective apps and/or they are incorporating more "**plug and play"** solutions with automatic system configuration when the product is connected. Manufacturers also offer smart plugs which operate between the socket and the power supply of the appliance. These smart plugs enable other products to be controlled wirelessly with an app, voice control or remote control e.g. turning ON/OFF or setting timers. Some smart plugs have an integrated power meter that monitors the power consumption and/or the energy consumption used by the appliance or device.

  Some manufacturers are also providing smart buttons as an alternative to the app. The **smart button** might include control of basic functions such as dimming and selecting between a few lighting scenes/modes.

The manufacturers of smart lighting report that they are engaged in an ongoing task to educate customers in the commercial sector around the full value of smart lighting as well as to provide proper training of staff to adequately manage and maintain smart, connected lighting systems [ref. 18].

- **Attempts to improve the user-friendliness by adding voice control**
  Manufacturer apps and home-automation systems attempt to increase the **user-friendliness by adding voice control**. Below are two examples of voice communication to an automatic lighting control system manager called "Lena":
  1. *Hey Lena, shift to a warm white tone and gradually dim the lights for 30 minutes until they switch off at 10 PM.*
  2. *Hey Lena, turn on gentle wake up at 06:30 and gradually increase brightness over 30 minutes to full light output.*
- **Simplification by selection between modes**
  Manufacturers are also trying to increase the user-friendliness by **selection between few fixed modes** (*e.g.*, read, concentrate, relax, and energise) as alternative to setting all the lighting parameters yourself.
- **If features are too complicated to use, energy savings may not be realised**
  In order to capture potential energy savings, users may choose to operate dimming and time scheduling of the lamp/luminaire. If the interface is not user-friendly, then these functions may not be used very much. This outcome would limit the energy savings, and the energy consumption might even be higher due to the extra standby that comes with smart lighting products.
- **Movement and/or daylight sensors are seldom included in smart lighting products**
  Use of movement and/or daylight sensors increase the potential **energy savings** substantially for some of the lamps/luminaires in the home, but these features are seldom included in the smart lighting products. In addition, research has shown that the mimicking of daylight variation including use of daylight sensors may improve the user's wellbeing, mood, and cognitive performance throughout the day.
- **Lack of interoperability**
  Within the same manufacturer's **product portfolio,** several countries have found that old gateways not connecting to new Lamps/luminaires in a series and vice versa. Furthermore, there is **no common platform** enabling functionality and interoperability between smart lighting products that use the **same communications protocol** but come **from different manufacturers.** This is not flexible and "binds" the customer to use one supplier's system. There is a need for open systems and apps.

One way this barrier could be solved is by controlling all smart lighting product functions and features through **home automation systems** such as Google Assistant, Amazon Alexa, Apple HomeKit, Samsung SmartThings, Flic, IFTTT, Homey, Logitech Harmony, Nest, Yonomi and others.

- **Need for integrated software/apps**
  Solutions to obtain interoperability could also be **integrating software/apps** that communicate with products using different protocols, wired networks and various home automation systems [ref. 20].

- **Standards and open systems needed**
  In commercial smart lighting, many of the current wireless communication systems are proprietary, causing a lack of openness across vendors and an inability to source products for best performance and cost. This limits the growth of connected networks and locks customers into a single vendor [ref. 18 and 19].

  The lighting industry **should establish a common set of standards** with respect to an **open and interoperable** environment. This would lower the risk of incompatible solutions and unexpected operating costs and provide flexibility for the specifier to select between compatible solutions. Without truly **open and interoperable** systems, proprietary and closed solutions will limit expansion and keep the deployment cost high.

- **Communications between wired and wireless systems in commercial buildings**
  In commercial buildings, the lack of **communication between wired systems** (e.g. using DALI) **and the wireless smart lighting** systems has been a barrier. A large step forward was made by the DALI Alliance which has, as shown in Figure 25, made:

  1. Specification Part 341 for a gateway between **Bluetooth and DALI** [ref. 22],
  2. Specification Part 342 for a gateway between **Zigbee and DALI** [ref. 22].

  These new specifications will be transferred to the IEC for incorporation into the next update of IEC 62386.

  With communication between wired and wireless systems being implemented, this frees up product developers from supporting multiple interface options in a new luminaire/lamp/sensor, enabling them to focus on features and user-oriented improvements.

  The ongoing **cooperation** between Zigbee Alliance and DiiA [ref. 10], DALI Alliance and Zhaga [ref. 8] and Zhaga and IEC [ref. 9] is highly relevant and important for addressing this barrier.

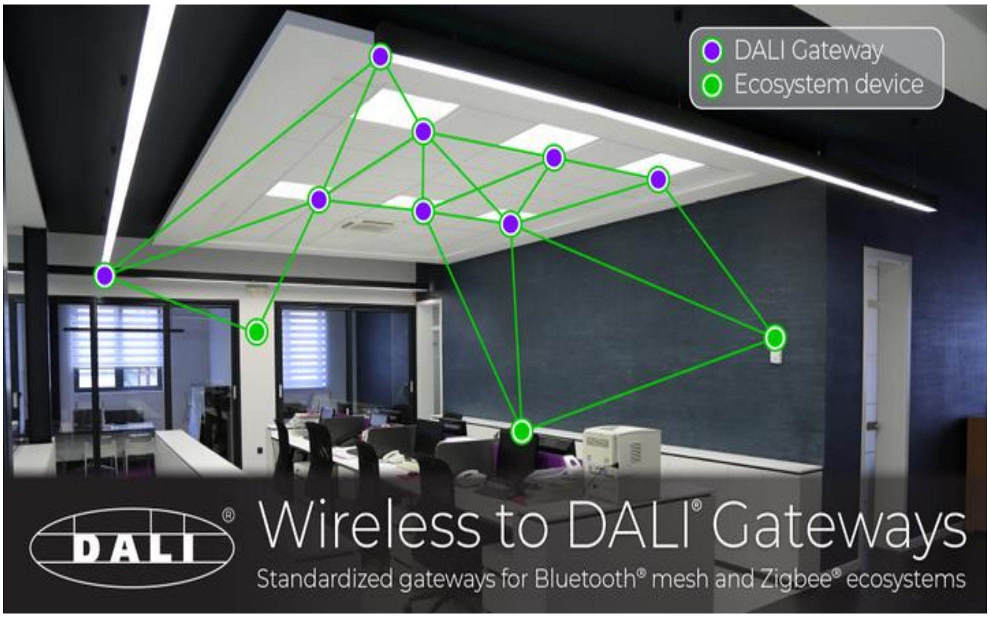

Figure 25. Communication between wired systems and wireless smart lighting

- **Need for future-proof products that are easy to upgrade**
  There is a need for development and sales of **future-proof luminaires** that are easily **upgradeable** to connectivity, Internet of Things (IoT) support and smart lighting. The US Department of Energy seeks to encourage this development [ref. 11].

6.3 Maximum Consumption in Buildings (kWh per m^2)

To achieve high energy efficiency for buildings, regulations often include requirements with energy consumption calculations based on the max power for lighting based on an assumed number of operating hours per day, month or year. This metric could be a barrier for use of smart lighting as the efficacy is often lower for smart lamps and luminaires.

That said, when a smart lighting system is installed in a building, the kWh/ m^2 consumption could be significantly lower and acceptable if the building manager makes use of energy-saving controls such as dimming and/or motion sensors.

The barrier above might be eliminated if the manufacturers add **self-reporting** of the energy consumption in the smart lighting product, but it must be **done accurately**. A DOE PNNL study from 2020 [ref. 17] investigated the reporting accuracy of connected lighting products with dimming and self-reporting of energy usage. The study found that instantaneous power measurements accuracy was within 2% but the cumulative energy consumption measurement **lacked precision** as high as 17%. **It is recommended to set appropriate accuracy requirements for energy consumption self-reporting in the standards for luminaires**. PNNL (USA) is trying to initiate work standardisation around this issue.

7 Conclusions and Recommendations for Policy Makers

The total energy impact of smart lighting products depends on the answers to the following questions:

- **How many people buy smart lighting products?** So far, it is estimated 5-10% choose smart lighting technology, but there is significant potential for higher levels of market penetration. Under the COVID 19 pandemic, many people worked from home and suppliers indicated that this gave a boost in the sales of smart lighting products. That sales boost has slowed now that the situation is returning to normal.
- **What features/services are included in the products purchased?** The trend to increasingly include new, non-lighting features in smart lighting products could increase energy consumption significantly depending on the standby power levels.
- **How well do the manufacturers inform the purchaser about standby power and variation in energy efficiency with dimming and colour-tuning?** Well informed consumers and businesses can choose the most energy efficient products appropriate for their need for dimming and change of colour temperature. In the present situation, lack of information may result in higher energy consumption than expected due to limited quality of the lighting products.
- **Are the smart lighting controls user-friendly?** This aspect is essential for how customers' use the products and the energy savings they achieve.

7.1 Test method for Smart Lamp/Luminaire Testing

The EU and the US DOE both have a test procedure for general LED lighting sources [ref. 14] with reference to IEC 62301 for standby, but neither of these test methods include testing of all smart lighting components and features.

In 2016, the IEA 4E SSL Annex outlined a test protocol that was used to conduct indicative testing of smart lamps/luminaires. This was coordinated with IEA 4E EDNA and their approach for collection of indicative non-laboratory approximate measurements. This report includes an update of the test protocol based on the experience with use of the previous published version.

It is recommended to consider including this test method in a regulation and/or a standard.

7.2 Overall Efficacy

The IEA 4E SSL Annex defined a new term "Overall Efficacy" which expresses luminous flux per unit energy consumed in both the ON mode and STANDBY mode. This metric captures both the product's performance and the use of that product. The usage has to be defined by an ON time and STANDBY time, *e.g.*, 2 hours/day and 22 hours/day respectively.

It is recommended the Overall Efficacy is used as a metric for data analysis and comparison of smart lighting products.

7.3 Maximum Standby Power Limits

In 2016, the first IEA 4E SSL Annex report [ref. 2] raised awareness of standby energy consumption and recommended maximum values of 0.5 W, 0.3 W and 0.2 W standby power for Tiers 1, 2 and 3 respectively. In the following years, a maximum standby power consumption of 0.5 W was implemented in US ENERGY STAR, EU Ecodesign regulation, Australia/New Zealand (proposed from 2024) and many African countries.

Between 2015 and 2020, the IEA 4E SSL Annex developed and analysed a database of 236 smart products shows, finding an average standby power of 0.51 Watts, while the lowest standby power for all these products was 0.08 Watts, and the median was 0.39 W.

In 2019, California adopted a maximum standby power limit of 0.2 W. In July 2022, the California database of compliant products contained 558 certified smart lighting products (see part 5.2) including smart lighting products that can be found elsewhere in the world from all the major manufacturers. These same products with a maximum 0.2 W standby power are also marketed in the rest of USA as documented by the ENERGY STAR database (see part 5.3) where as many as 81% (504 products) of the smart lighting products contained in the ENERGY STAR database had a maximum 0.2 W standby power.

The results of this policy-intervention in North America seem to have been achieved through the use of the IEEE Wake-Up Radio concept (see part 5.1). Using this concept, it is possible to lower the standby power down to 0.005 – 0.010 W without limiting or in any way constraining innovation.

Part 5.4 and 5.5 of this report show that standby power must be reduced to 0.01 W before the standby power consumption is insignificant. Therefore, the future goal for regulation should be to move the market towards a standby power limit of 0.01 W.

Table 12 includes the current and coming (2024) recommended standby power requirements in the SSL Annex's quality and performance tiers [ref. 1] as well as the future goal.

Table 12. Maximum standby power in IEA 4E SSL Annex Tiers

Year	Tier 1	Tier 2	Tier 3
2016 – 2022	0.5 W	0.3 W	0.2 W
2024 -	0.2 W	0.15 W	0.1 W
Future goal	0.01 W[9]		

[9] It is no problem to measure relatively small load at this level as the measurement equipment can be adjusted to the appropriate measurement range and tolerance for verification.

7.4 Gateway

The typical power consumption for a gateway is found to be 1.5 W (see part 4.3). A gateway can typically support communication for up to 50 lamps/luminaires. It is estimated that most domestic customers have 5 smart lighting products or less. It is found that the gateways share of the total annual energy consumption is 60% in case of 1 smart product, 33% in case of 3 smart products, 23% in case of 5 smart products and 13% in case of 10 smart products in the home.

It is recommended to require the manufacturers provide information about the power consumption of the gateway. It is recommended the manufacturers find ways to lower the constant gateway power consumption considerably e.g., by use of the wake-up concept. Future regulation might include a maximum power limit for the gateway.

7.5 Rated Performance for at least two CCT's for colour tuneable products

Many smart lighting products include the option of colour tuning, however until recently, manufacturers only provided product performance data for one CCT, even though lumen output and efficacy may vary considerably. The declared efficacy for most products occurs at 4000 K or 6500 K (see part 4.7) and the luminous flux can be as much as 56% lower at 2700 K. An ideal solution would be for the manufacturer to provide the luminous flux, power and efficacy for all the nominal CCT's within a smart lighting product's selectable range.

It is recommended to require the manufacturers at least provide information:

1. **On the package and online about the luminous flux, power and efficacy for two CCT's: 2700 K (warm colour) and 4000 or 5000 K (cool colour)**
2. **Note online the CCT ranges where the luminous flux is less than 70% of the maximum achievable luminous flux.**

7.6 Information about the efficacy for dimmable products

Most smart lighting products include dimming. For a proportion of the smart products, efficacy decreases with increased dimming. To determine the energy savings from dimming, manufacturers would have to declare the smart products efficacy at defined dimming levels.

It is recommended to require that the manufactures provide rated information about luminous flux, power, and efficacy for the dimming levels: 75%, 50% and 25% light output for the CCT factory default setting.

7.7 Control and reduction of standby power for non-lighting features

More and more smart lighting products include non-lighting features e.g., sensors, WiFi booster, speakers, and cameras. These features are often always ON, resulting in a much higher STANDBY power. The lack of possibility for activation and deactivation makes it impossible to limit this additional energy consumption.

It is recommended that regulators require the manufacturers:

- **Make it possible to switch extra non-lighting features ON and OFF so that end-users can disable features they may no longer want or need. This could lower the STANDBY energy consumption.**
- **To consider using the wake-up STANDBY technology for these functions as these new consumptions can be considerable larger than the lighting consumption.**

7.8 Awareness Raising

Since 2016, the IEA 4E SSL Annex has raised awareness of standby energy consumption and others issues for smart lighting including press releases (http://ssl.iea-4e.org/news/smart-lighting) and presentations at conferences, seminars and workshops [ref. 3, 4, 5, 6 and 7].

It is recommended that governments, industry, researchers and other stakeholders continue to raise awareness on smart lighting issues as there is still a significant potential for making smart lighting more energy efficient and capturing energy savings while enhancing the user experience.

7.9 Energy Saving Potential – Need for End-use Research

When smart lighting was introduced, the focus was on the smart wireless control of dimming, colour tuning, scheduling etc. There has been focus on the increased comfort and actually on improving the user’s wellbeing, mood, cognitive performance and health throughout the day by mimicking daylight variation. This effect can be controlled through the use of daylight sensors.

Smart lighting can also be used to promote energy savings, but this has not been the main focus thus far. In order to quantify the potential for energy savings from smart lighting, research is needed on:

- What smart lighting products are being sold?
- How energy efficient are those smart lighting products?
- What features are included?
- What is the standby power when adding non-lighting features?

- Where is the smart lighting being installed and how much is it used?
- What is the operation time?
- What are the barriers for better energy saving use of smart lighting?
- How could the energy savings and user-friendliness be improved?
- What energy saving features could be added?

The above should be investigated both for the domestic and professional sectors

It is recommended to conduct end-use lighting research to estimate the energy saving potential of smart lighting and what would be needed to realise this potential.

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