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Evaluating the standby power consumption of smart LED bulbs

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ABSTRACT

There is an increasing demand for smart devices in recent years. One of the latest additions to the long list of these smart devices is the smart light-emitting diode (LED) light sources. They offer many additional features in addition to provide light. However, like all other smart devices, when they are turned off by the user through a smart device, they still consume energy. That standby power consumption, when the bulbs are off, soon becomes an increasing load to the grid.

In this study, we investigated the current smart residential LED bulb market and selected three samples from 30 models that are available to Canadian consumers. We tested the standby power consumption of those samples by following the IEC 62301 standard.

The results showed that the standby power consumption of 21 Smart LED bulb models (out of 30) was less than 0.5 W, which resembles the maximum allowable standby power consumption amount of a smart LED bulb, if the manufacturers intend to carry the Energy Star logo on their product. Although most products are not Energy Star rated, it is a promising result.

We also found that the standby power consumption of the three bulb samples tested for each model was generally consistent (the standard deviation was less than 0.02). Only three models had one sample measured with a higher or lower consumption than the other two samples (highest difference 0.43 W, lowest difference: 0.06 W, standard deviation higher than 0.03). This internal consistency or standby power consumption amount in between samples are worrisome.

Although our sample size was small, we believe that the findings from our study enabled to gather enough information to have a basic idea about the status of current standby power consumption of the smart LED bulbs in Canadian residential market

1. Introduction

Devices and appliances in daily life are becoming smart enough to interact with their users due to recent developments in digital technology. Designers and manufacturers develop new smart products every day, in response to a high demand from users of smart devices. For instance, a smart refrigerator can send an updated shopping list as a message to its owner to replenish missing foods, or the lights in a house can turn on automatically to welcome the owners as soon as they parked their car.

The light emitting diode (LED) technology developed rapidly in the last decade. Considering their energy efficiency, LEDs were initially marketed as an alternative to conventional light sources. However, lighting manufacturers quickly realized that the potential of the LED technology is not limited to just energy savings or other advantages, such as their long lifetime or robustness. LED lighting technology can also be implemented into home automation systems or have embedded functions such as security cameras, Wi-Fi signal repeaters or speakers.

Many manufacturers combined the potentials of the LED technology with the advantages of mobile smart devices and started to develop smart LED bulbs. Users, who used to turn on and off their light sources with a single wall switch, now also have the option to control the smart LED bulb's spectral output to create a different atmosphere in their environment by using applications on their smart devices. Users don't even have to be in the same room to make those changes and they can interact with their light sources from anywhere in the world, as long as they have an Internet connection.

Although this high level of connectivity to the light bulb introduced some benefits to the users, it also came with a hidden cost: standby power consumption. When a user turns off a smart LED bulb from a mobile device, the bulb stops emitting light; however it is constantly consuming power. Until recently, this standby power consumption used to be a problem only for devices such as televisions; however, it is now beginning to be a serious problem with the rapid increase of smart LED bulbs sales worldwide.

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Table 1
The smart LED models we selected to test.

Model	Source or procuring	Lumen output (lm)	Comm.	Price (CAD)*	# of bulbs/package
1◊	Best Buy	800	Android	$129.99	2**
2◊	Best Buy	600	Android	$199.97	3**
3◊	Best Buy	750	Android	$69.97	2**
4	Best Buy	800	Android	$59.98	1
5	Home Depot	800	Android	$14.98	2
6	Home Depot	550	Android	$59.99	1
7	Canadian Tire	800	Android	$19.99	1
8	Staples	530	Android	$44.99	1
9◊	Best Buy	800	Android	$34.99	1
10◊	Best Buy	800	Android	$39.99	1
11◊	Best Buy	800	Android	$59.99	1
12	Best Buy	1100	Android	$74.99	1
13◊	Manufacturer's store	980	Android	$26.99	1
14◊	Manufacturer's store	1000	Android	$13.99	1
15	Lowe's	800	Android	$79.99	2**
16	Lowe's	805	Android	$84.99	1**
17	Ebay.ca	600	Android	$17.48	1
18	Ebay.ca	500	IOS	$59.23	1
19	Amazon.com	500	Android	$75.93	1
20	Amazon.ca	550	Android	$34.99	1
21	Amazon.ca	600	Android	$49.95	1
22◊	Amazon.ca	800	Android	$64.99	2**
23◊	Amazon.ca	800	Android	$74.99	2**
24	Amazon.ca	810	Android	$36.99	1**
25	Amazon.ca	800	Android	$64.64	1
26	Ebay.ca	550	IOS	$29.47	1
27	Amazon.ca	800	Android	$51.91	1
28	Amazon.ca	550	Android	$22.99	1
29	Manufacturer's web store	800	IOS	$69.99	2
30	Amazon.ca	815	Android	$19.46	1

* The prices are as of July 2017, excluding additional costs such as currency conversion, tax and shipping.
** These products are generally named as "starter kits" and include a hub in the package, which increases the price.
◊ Models (1, 2, 3), (9, 10, 11), (13, 14) and (22, 23) are manufactured by the same company.

The compound annual growth rate of the global smart LED lighting market from 2018 to 2023 is estimated to be 21.5% [7] and it is clear that their standby power consumption will be an important issue in a near future [6].

This study focuses solely on the standby power consumption of smart LED bulbs. Three samples of 30 smart LED bulb models were measured by following the globally accepted IEC 62301 test procedure for standby power measurements.

2. Standby power consumption measurement method

2.1. Samples

The following conditions and considerations were taken into account when selecting the sample models for testing:

The primary focus was to test smart LED bulbs that are designed for residential applications; therefore the bulbs had to have an omnidirectional A19 form (familiar "Edison bulb" look) and an E26 (medium base) socket (most dominant residential socket size). Bulbs also had to have a lumen output of at least 500 lm.

For this study we selected 30 LED bulb models from 20 different manufacturers. Three samples from each chosen LED bulb model were purchased and tested for their standby power consumption. We aimed to select samples that represented a wide range of function, quality and price options, but more importantly, they should all be available to Canadian consumers both online and in store purchase. Table 1 summarizes the basic properties of the samples, including lumen output.

Fig. 1 summarizes the distribution of the properties of the selected smart LED bulb samples as procurement sources, approximate price per bulb (including the cost of the hub, if the retail package comes with it or if the operation of the model requires it) and operating system of the application that controls the model.

Assuming an average Canadian consumer has access to both online and in store purchases; we used both sources to procure the samples of smart LED bulbs. Among the selected 30 models, 14 products (47%) were procured from online retailers (e.g. Amazon.ca, Ebay.ca) and 16 products (53%) were procured from local brick-and-mortar stores (e.g. Best Buy, Canadian Tire, Home Depot).

Affordability was another criterion for sample selection. The bulb prices in our sample ranged from $7 to $75,[1] depending on factors such as manufacturer or additional functions. Eight samples (27%) were less than $30 per bulb, 11 samples (36%) were in the $31–$50 range and 11 samples (37%) were more than $51.

Currently there are two mobile operating systems used by smart devices: Android and IOS. The majority of the samples (27) could be controlled by both operating systems, whereas three samples could be controlled by the IOS operating system only. All applications (also known as "apps") for the selected models, regardless of running on IOS or Android, were available to download for free.

There were three different types of connection protocols in our samples; Bluetooth, Wi-Fi and Hub (Gateway). The Bluetooth wireless technology allows devices to communicate or transmit data and/or voice wirelessly over a short distance [1]. Those products are usually sold as bulbs only and they do not need a hub or a gateway. This lowers the retail prices and the potential complications that users might experience during the installation. However, with Bluetooth wireless technology enabled LED bulbs, it is not

[1] Note that, for some samples the sale price includes the additional hardware such as the hub or gateway, therefore, this reflects as an additional cost in the $cost/bulb calculations.

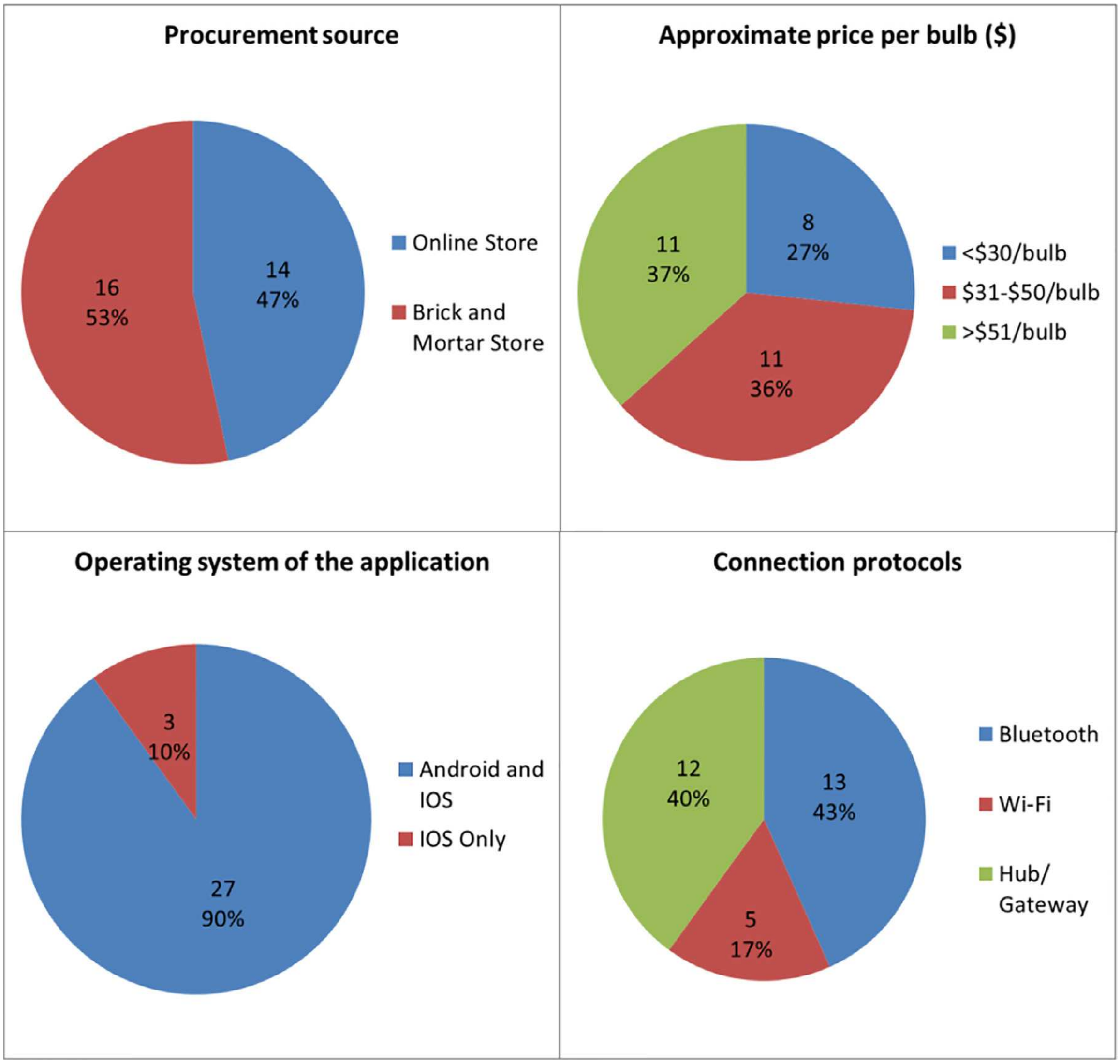

Fig. 1. Selected properties of the smart LED bulbs samples.

possible to control the lights remotely or from a long distance[2]; the user must be within a certain distance from the device for continuous communication. We selected 13 models, which were controlled by Bluetooth wireless technology.

Wi-Fi products need a router and a continuous Internet connection. Once the smart device is connected to the private local network through the router, it is possible to control the device from anywhere in the world as long as the user has access to the Internet. In this study we tested five models that used Wi-Fi communication.

Some smart LED bulbs require a hub or gateway to operate. A hub is physically connected to the router by an Ethernet cable and it is usually used as the access point of an individual or group of smart devices. It is safer and more secure to have a dedicated access point to control multiple LED bulbs in multiple rooms or spaces. Those products are usually sold as starter kits, which include one hub and one or two LED bulbs. Consumers can purchase additional individual LEDs, if they wish to have more bulbs in their space and expand the size of their lighting network. These products can also be connected to a hub that is usually part of a smart home. There is a growing market for connected smart devices and connecting LED bulbs to a hub with other devices (e.g. thermostats, cameras, televisions, plugs, etc.) makes it very easy to operate by the user. In this study we tested 12 samples that required a hub to operate.

Although the simple and primary function expected from a light bulb is to emit light, in the case of smart LEDs, nearly all samples had an additional function such as a timer, scheduling, message and call alert, energy monitoring, music visualization and playback pre-set light scenarios. However, the most dominant additional function among the tested samples was the “tunable color temperature”, which enables users to change the appearance of the white light output (warm, neutral or cool white) to create a different atmosphere in the living environment.

2.2. Measurement standard and procedure

The internationally recognized standard for standby power measurement is IEC 62301 [5]. It is prepared by the International Electrotechnical Commission (IEC) and used by numerous authorities worldwide as a guide for standby power measurements.

The IEC 62301 standard defines its objective as “a method to test and to determine the power consumption of a range of prod-

[2] Smart LED bulbs usually use Class 2 Bluetooth Communication protocol and transmit signals at 2.5 mW, with a range of approximately 10 m (32 ft.) [8].

ucts on relevant low power modes, generally where the product is not in active mode (not performing its primary function)". The IEC standard also defines the "low power mode" as a product mode that falls into one of the three broad mode categories,[3] which are described as:

- Off mode: Any product mode where the energy using product is connected to a main power source and is not providing any standby mode, network mode or active mode function and where the mode usually persists. An indicator that only shows the user that the product is in the off position is included within the classification of the off mode.
- Standby mode: Any product mode where the energy using product is connected to a main power source and offers one or more of the following user-oriented or protective functions which usually persist:
  - To facilitate the activation of other modes by remote switch, internal sensors or timer;
  - Include a continuous function: information or status displays including clocks;
  - Include a continuous function: sensor-based functions.
- Network mode: Any product mode where the energy using product is connected to a mains power source and at least one network function is activated, but where the primary function is not active.

The IEC 62301 standard covers all smart household electrical appliances and it is not written to be used specifically to measure smart LED bulbs. Therefore, the definitions of these three modes are not very clear and in our case, it was not easy to select one specific mode to define the function of smart LED lighting products.[4]

In this study, we accepted that when a smart LED bulb is turned off by using the application on a smart device (which can be accepted as a "remote switch", as defined by the IEC standard); the bulb is in a "standby mode".

For this study, we developed a procedure to measure the standby power of smart LEDs and applied strict and detailed requirements with respect to the test equipment specifications, environment and procedure, using the IEC 62301 standard as reference. We added one step to the test procedure, which is not required by the IEC standard, but is a requirement of the U.S. Department of Energy test procedure methods[5] specified at 10 CFR 430, Appendix BB [2]: We monitored the Internet connectivity throughout the tests to ensure that the tested smart LED bulbs, as well as the smart device that controlled the bulb and the hub or gateway (if available) had an uninterrupted network connection. This did not interfere with the requirements of the IEC standard, but added confidence in the accuracy of the results. We strongly believe that this type of monitoring is necessary for measuring standby power consumption of smart LED bulbs; if the bulb loses communication with the router or gateway, it may try to reconnect, which will result in increased power consumption.

2.3. Devices

Power supply: We used an IT7322 programmable power supply from ITech. This power supply fulfills all the required specifications of the IEC 62301 standard. It also meets the IEC 61000-3-2 requirements, which specify the required supply voltage waveform.

Power meter: IEC 62301 standard requires a power meter with certain functions to measure the standby power consumption of the devices tested. The Yokogawa WT310E power meter we used meets all those requirements, including the "harmonics function" required by this standard.

As mentioned earlier, the IEC 62301 standard is not written specifically for smart LED devices, therefore it can be used to test a vast variety of smart devices. Depending on the device to be tested and its standby power consumption, the configuration of the electrical connection between the power meter, the power supply and the tested product can vary. Since the standby power consumption of smart LED bulbs fall into the "low power load" category, as defined by the IEC standard, we did the recommended connection arrangements (voltage measured on the supply side of the current sensor of the power meter).

Tools to measure the test environment: The IEC 62301 standard requires that the standby power measurements must be carried out in a room that has an air speed close to the product under testing of less than 0.5 m/s. The ambient temperature should also be maintained at 23 ± 5 °C throughout the test. We used a multi-function ventilation meter with an articulated probe (TSI/Alnor 9565-A Veloci Calc®) to monitor the test environment and validate that the air velocity and temperature parameters were within the acceptable range. Note that all the three devices listed above had valid calibration certificates at the time of testing.

Test software: Yokogawa, the manufacturer of the power meter, offers software designed specifically for measuring the standby power consumption, which meets all the requirements of the IEC 62301 standard [9]. We preferred to use this software, because of its useful features, such as a built-in checklist. It is very useful for the user to avoid missing any steps before and during the measurement. After the test is completed, the software generates a report, which includes the total harmonic distortion (THD) measurement, crest factor, root mean square (RMS) voltage, as well as the frequency and measurement period, in addition to the standby power consumption measurement.

Smart devices: The IEC 62301 standard does not specify any properties for the smart devices used to control the products to be tested. In our case, all smart LED bulb samples were controlled by an application installed on a smart device.[6] We used an Apple IPad (IOS) and a Samsung Tablet (Android) for our test, as dedicated smart portable devices for this project. We deleted all previous data and applications on both devices and reset them to factory settings before testing. We also identified and downloaded all the applications needed to control the samples, from the App Store (IOS) and the Google Play Store (Android).

Router: An Internet connection was required to test all models without a Bluetooth wireless technology. A private network was established in our laboratory, dedicated only to this project. We used a LinkSys AC1200 Dual-band Wi-Fi router. We kept all factory settings, except for the wireless frequency, because all of the selected smart LED bulb models with Wi-Fi and hub connection required a frequency of 2.4 GHz.

3. Standby power measurement results

We tested three samples from 30 selected smart LED bulb models using the procedure and equipment described above.

Table 2 summarizes the standby power results, including the minimum, maximum and average standby power consumption. We

[3] The standard, however, added a note to that definition and highlights the fact that not all low power mode categories are present on all products, which is true for smart LED bulbs.

[4] Refer to the Econoler white paper for more information about various attempts to find a better clarification of the standby mode of smart lighting systems [3].

[5] "Section 5.2.Test Method, Measurements, and Calculations Lamp" clearly states that the "lamp must remain connected to the network throughout the duration of the test".

[6] There are various smart LED products that can be controlled by a hand-held remote control, including on/off control, changing the CCT or the color of the light output.

Table 2
Standby power measurement results of the sample products.[7]

Model number	Standby power consumption of individual samples (W)			Standby power consumption analysis			
	S1	S2	S3	Min.	Max. (W)	Average (W)	St. Dev.
1	0.40	0.39	0.38	0.38	0.40	0.39	0.01
2	0.36	0.37	0.37	0.36	0.37	0.37	0.00
3	0.35	0.35	0.34	0.34	0.35	0.35	0.01
4	0.98	0.99	1.01	0.98	1.01	0.99	0.02
5	0.34	0.38	0.38	0.34	0.38	0.37	0.02
6	0.20	0.21	0.21	0.20	0.21	0.21	0.01
7	0.35	0.33	0.34	0.33	0.35	0.34	0.01
8	0.20	0.22	0.24	0.20	0.24	0.22	0.02
9	0.59	0.58	0.60	0.58	0.60	0.59	0.01
10	0.57	0.59	0.59	0.57	0.59	0.58	0.01
11	0.82	0.81	0.81	0.81	0.82	0.81	0.01
12	0.48	0.48	0.48	0.48	0.48	0.48	0.00
13	0.40	0.39	0.39	0.39	0.40	0.39	0.00
14	0.28	0.27	0.28	0.27	0.28	0.28	0.00
15	0.37	0.39	0.39	0.37	0.39	0.38	0.01
16	0.42	0.36	0.41	0.36	0.42	0.40	0.03
17	0.45	0.46	0.46	0.45	0.46	0.46	0.00
18	0.80	0.68	0.69	0.68	0.80	0.72	0.07
19	0.83	1.26	1.26	0.83	1.26	1.12	0.25
20	0.47	0.47	0.48	0.47	0.48	0.47	0.01
21	0.27	0.28	0.28	0.27	0.28	0.28	0.00
22	0.44	0.44	0.44	0.44	0.44	0.44	0.00
23	0.35	0.35	0.35	0.35	0.35	0.35	0.00
24	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25	0.46	0.65	0.42	0.42	0.65	0.51	0.12
26	0.09	0.09	0.09	0.09	0.09	0.09	0.00
27	0.73	0.79	0.91	0.73	0.91	0.81	0.09
28	0.34	0.37	0.34	0.34	0.37	0.35	0.02
29	0.35	0.36	0.35	0.35	0.36	0.35	0.00
30	0.25	0.25	0.25	0.25	0.25	0.25	0.00

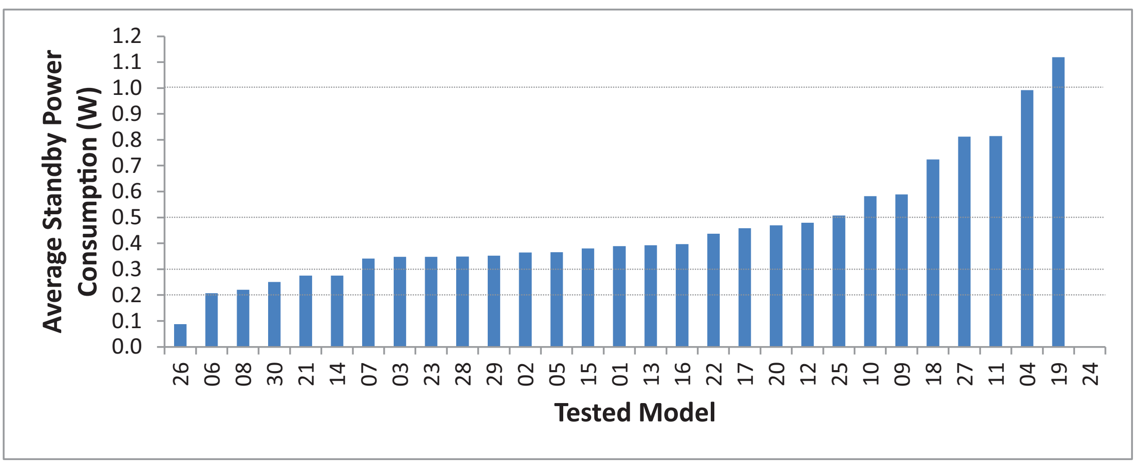

Fig. 2. Average standby power consumption of selected smart LED bulbs models.

included the standard deviation of the standby power consumption among the three samples tested to show the difference.

The results showed that the majority of the tested smart LED bulbs (21) used less than 0.5 W in stand-by mode, and only eight models used more than 0.5 W. Fig. 2 shows the average standby power consumption of the tested models in an ascending order.

Data also showed that for 24 models, all three samples tested used very similar amounts of power except for few cases (Fig. 3). The measurements among the three samples of the majority of the models were generally consistent. Only five models (16, 18, 19, 25 and SP2) had a standard deviation of more than 0.03 (see Table 2).

3.1. Comparing measured values with manufacturer's claimed values

In our sample, ten smart LED bulb models had their standby power consumption already measured by their manufacturers. The information about standby power consumption values and other detailed information about the products can be found either on the retail package or on the manufacturer's web page (product specification link). Note that although the standby power consumption values of those ten products are publicly available, this data may not necessarily be accessible to all customers (e.g. printed text on retail packages), especially at the time of shopping. Only Model 17 had the standby power consumption of the LED bulb listed on its retail package. We compared the claimed standby power consump-

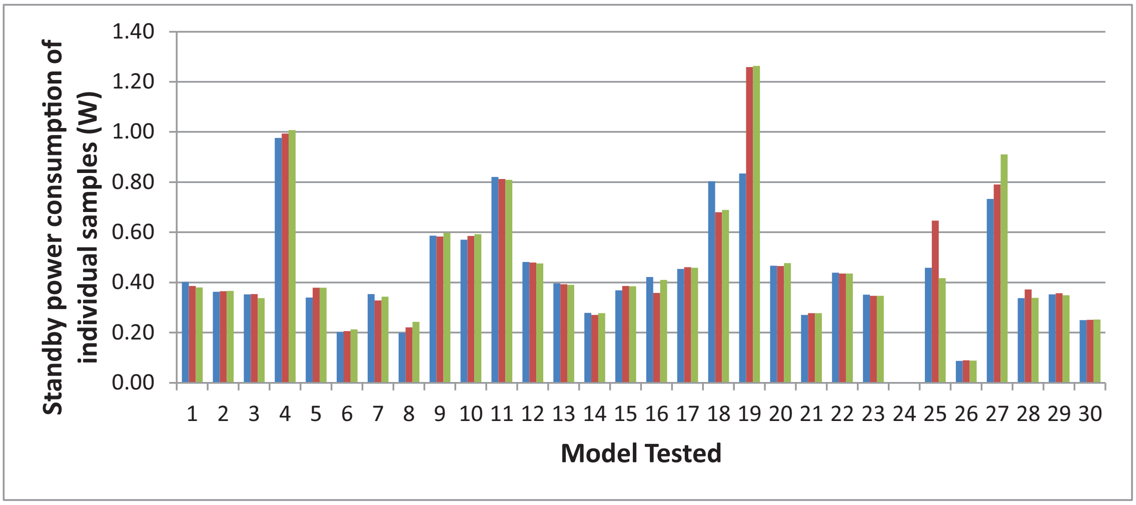

Fig. 3. Standby power measurement results of three samples of each model.

Table 3
Comparison of claimed standby power consumption versus our results.

Model number	Standby power consumption (W)							
	Claimed by the manufacturer	Our measurement results						
		Sample 1	Sample 2	Sample 3	Minimum	Maximum	Average	Difference*
1	**0.1**	0.40	0.39	0.38	0.38	0.40	**0.39**	+0.29
2	**0.2**	0.36	0.37	0.37	0.36	0.37	**0.37**	+0.17
3	**0.2**	0.35	0.35	0.34	0.34	0.35	**0.35**	+0.15
9	**0.55**	0.59	0.58	0.60	0.58	0.60	**0.59**	+0.04
10	**0.55**	0.57	0.59	0.59	0.57	0.59	**0.58**	+0.03
11	**0.5**	0.82	0.81	0.81	0.81	0.82	**0.81**	+0.31
12	**0.55**	0.48	0.48	0.48	0.48	0.48	**0.48**	−0.07
13	**0.5**	0.40	0.39	0.39	0.39	0.40	**0.39**	−0.11
14	**0.5**	0.28	0.27	0.28	0.27	0.28	**0.28**	−0.22
17	**0.5**	0.45	0.46	0.46	0.45	0.46	**0.46**	−0.04

* The difference between the standby power consumption of the tested product, claimed by the manufacturer and the average result we found by measuring three samples.

tion with our measurement results and the result can be seen in Table 3.

Our results showed that the average standby power consumption of Models 1, 2, 3, 9, 10 and 11 were higher than the values claimed by the manufacturer. The values measured for Model 9 and Model 10 were slightly higher than the manufacturer's claimed values (0.04 W and 0.03 W). Although the standby power consumption of Model 2 and Model 3 is not very high compared to the claimed values (0.17 W and 0.15 W), in the case of Model 1 and Model 11, there is a significant difference (0.29 W and 0.31 W) between the measured and the manufacturer's claimed standby power consumption (0.1 W and 0.5 W compared to our average measurements of 0.39 W and 0.81 W). Since all three samples of those two models consistently showed higher values, we are confident that the standby power consumption of these two models is much higher than that claimed by the manufacturers.

For Models 12, 13, 14 and 17 our measurements showed that the maximum standby power consumption was lower than the manufacturer's published values. Especially in the case of Model 14, the measured average standby power consumption was 0.28 W for all three samples, which is significantly lower than the manufacturer's claimed value of 0.5 W.

Manufacturers of seven models claimed that their smart LED products are consuming either 0.5 W or 0.55 W at standby mode. Although the source for 0.55 W is not clear, 0.5 W would be the maximum allowable standby power consumption of a smart LED bulb, if the manufacturers intend to carry the Energy Star logo on their product [4]. Therefore, it seems like some manufacturers aimed to keep the standby power consumption of their product below that level, although their products did not carry the Energy Star logo. Only three models (Models 1, 2 and 3), manufactured by the same company, had the Energy Star logo on their products and used less than the 0.5 W upper limit, as required.

3.2. Categorizing the models according to the IEA tiers

Measurements for six parameters (energy-efficiency, life, color, operation, health and environment) are required to define the three performance tiers of the IEA [6]. However, due to time and budget constraints, in this study, we collected data for only energy-efficiency; therefore, the content of this section is for information purposes only.

Table 4 summarizes the values for efficacy and maximum standby power, defined for energy-efficiency parameter, required to categorize the smart LED products into one of the three performance tiers.

Efficacy calculations require the lumen output and the power consumption data of the light source at default state. We used the manufacturer's claimed values for the lumen output and power consumption values, assuming that they were measured when the bulb was at default state. However, most of the LED bulb models have various output modes and the lumen output and power

Table 4
The three performance tiers defined by IEA.

		Tier 1	Tier 2	Tier 3
Energy-efficiency parameter	Efficacy (lm/W)	65 (65–89)*	90 (90–124)*	≥ 125
	Maximum standby power (W)	0.3 (0.5–0.31)*	0.5 (0.3–0.21)*	≤ 0.2

* The ranges of the values in parentheses are our addition to the table.

Table 5
Categorizing models according to IEA tiers.

	Power Consumption (W)					IEA's quality and performance tiers per measured:	
Sample Number	**On, at default state** (claimed)	**Equivalent to incandescent** (claimed)	**Maximum, Stand-by** (measured)	**Lumen output** (claimed)	**Efficacy (lm/W)** (claimed)	**Standby power consumption**	**Efficacy**
1	10	60	0.40	800	80	T 1	T 1
2	10	60	0.37	600	60	T 1	N/A
3	9.5	60	0.35	750	79	T 1	T 1
4	10	60	1.01	800	80	N/A	T 1
5	10	60	0.38	800	80	T 1	T 1
6	9.5	60	0.21	550	58	T 2	N/A
7	9	60	0.35	800	89	T 1	T 1
8	7	40	0.24	530	76	T 2	T 1
9	11	60	0.60	800	73	N/A	T 1
10	11	60	0.59	800	73	N/A	T 1
11	11	60	0.82	800	73	N/A	T 1
12	11	75	0.48	1100	100	T 1	T 2
13	12	N/A	0.40	980	82	T 1	T 1
14	12.5	N/A	0.28	1000	80	T 2	T 1
15	12	60	0.39	800	67	T 1	T 1
16	9.5	60	0.42	805	85	T 1	T 1
17	6	N/A	0.46	600	100	T 1	T 2
18	8	60	0.80	500	63	N/A	N/A
19	8	60	1.26	500	63	N/A	N/A
20	8	N/A	0.48	550	69	T 1	T 1
21	7.5	40	0.28	600	80	T 2	T 1
22	9.8	60	0.44	800	82	T 1	T 1
23	9.8	60	0.35	800	82	T 1	T 1
24	9	60	N/A	810	90	N/A	T 2
25	7	N/A	0.65	800	114	N/A	T 2
26	6	N/A	0.09	550	92	T 3	T 2
27	9	60	0.91	800	89	N/A	T 1
28	7.5	60	0.37	550	73	T 1	T 1
29	10	60	0.36	800	80	T 1	T 1
30	11.5	60	0.25	815	71	T 2	T 1

Note that if the model does not have a tier classification and is represented by "N/A", it is because the measured value is above or below the tier range.

consumption values may not be necessarily measured by the manufacturer when the product is at default state. We used the results from our standby power consumption and photometric measurements to define the "maximum standby power".

Table 5 shows how our 30 samples fitted the IEA's quality and performance tiers by using the above mentioned assumptions. It is important to note that when categorizing the tested smart LED bulb models, there are multiple unknown and unclear values. Therefore, the classification approach in this table is for information and discussion purposes only. The IEA tier categorization is a combination of multiple parameters, so it is not right to use only one parameter to categorize a model.

Among 30 LED bulb models, 12 of them fit to Tier 1 for both standby power consumption and efficacy values. Some products fit to only one of these two measurements (six models Tier 1 only, three models Tier 2 only). In some cases, the LED model fits to one tier for one measurement and another tier for the second measurement (six models Tier 1/Tier 2 and one model Tier 2/Tier 3). Only two models did not fit to any of the three IEA performance tiers.

4. Discussion

We measured three samples from each selected LED bulb model. The standby power consumption of some of the three samples for various models showed significant differences. For instance, the first sample of Model 19 (19-S1: 0.83 W) used less standby power than the other two samples (19-S2: 1.26 W and 19-S3: 1.26 W). The second sample of Model 25 (25-S2: 0.65 W) used more than the other two samples (25-S1: 0.46 W and 25-S3: 0.42 W). We purchased all three samples from the same supplier, and checked the version and batch number of the samples to ensure that they all matched, so different manufacturing time or location would not be the cause of that difference. In both cases, the consumption of the other two samples was very close to each other. These differences could be due to a random anomaly, however, they could also be due to the low quality of the product components, or just due to a random defective product that misses the quality inspection. It is impossible to know the real reason behind these differences with such a small sample size.

The standby power consumption of 21 models was less than 0.5 W. As mentioned, 0.5 W is the highest acceptable standby power consumption of smart LED bulbs to have the Energy Star rating. Only three of the 30 samples (Models 1, 2 and 3) had an Energy Star rating (all three models were manufactured by the same company) and it is not clear if the remaining 27 products intended to meet any other energy-saving program. However, most of the manufacturers aimed to keep the standby power consumption of their products lower than a certain value. This indicates that manufacturers pay attention to the standby power consumption, while they are designing their smart LED products.

The sample size in our study was very small, therefore, it is not easy to identify the exact characteristics of the standby power consumption of the selected smart LED bulb models and reach solid conclusions.

5. Conclusion

In this study, we tested the standby power consumption of three samples from 30 smart LED bulb models, by following IEC 62301 standard. Our sample size was too small for reaching any solid conclusions, but some key findings from this project are highlighted below:

- The standby power consumption of 21 Smart LED bulbs models (out of 30) was less than 0.5 W.
- Generally, the standby power consumption of the three bulb samples tested for each model was consistent (the standard deviation was less than 0.02). Only five models included one sample that presented a higher or lower consumption than the other two samples (highest difference 0.43 W, lowest difference: 0.06 W, standard deviation higher than 0.03).

Due to the limited time and budget, it was not possible to categorize all 30 samples to the IEA's quality and performance tiers. However, if we use only both standby power consumption and efficacy to categorize the tested models, 12 models are Tier 1 only.

The results of this study provided an overview of the current status of the smart LED lighting products available for Canadian consumers. However, more detailed investigation should be carried out in the future to gain a better understanding about these lighting products:

- Increasing the sample size would provide more robust data and would better identify the properties of the various smart LEDs models available on the market. However, selecting a large quantity of models and a large number of samples from each model may not be a cost-effective approach. The results of this study already separated the tested LED products into certain groups, such as the IEA Tiers. In future studies, fewer models could be selected to represent each group, and a relatively larger number of samples from each model should be tested.
- In our tests, due to time constraints, we decided to procure each LED model from the same vendor. It was a safe strategy to avoid potential delays due to shipping. However, acquiring samples from different vendors and various locations across Canada would give a more diverse sample range. We believe that different production batches with potentially different properties (production plant, date of manufacturing, firmware version, etc.) of the same product would generate more robust results.
- In future studies, when calculating the standby power consumption of models with a hub, the hub's consumption should be measured separately and added to the total consumption. This way, the consumption of the models with a hub could be compared separately if needed.
- Our photometric test results indicated that the measured CCT values of "constant CCT" products were quite close to the values claimed by the manufacturers. However, we did not see that accuracy for the models with "tunable CCT". Unless this was due to the design of the application (no option for users to select a specific CCT value), the reason for this inconsistency must be investigated to provide recommendations to the manufacturers.
- Each model we tested, unless manufactured by the same company, came with a custom application to access to the functions of the LED product it controlled. During testing, we observed that some applications were very easy to use whereas others were not. A human factors study designed to evaluate the user's ability to use features such as color temperature or light level changing would be particularly valuable. Identification of potential issues would help manufacturers improve their future software and interface design.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.enbuild.2019.01.019.

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