Not so clever when they are off: standby power use in smart lamps

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Abstract

Smart lamps, or wirelessly controllable lamps, represent one of the fastest growing residential lighting market segments, as well as one of the first products in the category of the Internet of Things. The rapid growth of smart lamps can be traced to the convergence of two market developments: (1) the emergence of LED lighting, which can readily offer dimming as well as enhanced control features such as colour tunability and (2) the ubiquity of wireless networks and smart phones, which allow consumers to easily send control signals to the lamps. Today, dozens of manufacturers have smart lamps on the market.

During normal operation (or active mode), smart lamps can be expected to be efficient devices. The lamps rely on LEDs, which continue to post impressive improvements in efficacy, and add features, such as dimming and scheduling, that could decrease energy use even further. However, smart lamps risk compromising much of the energy they save because of their standby losses. Unlike traditional lamps that use no power when turned off, smart lamps use power for their communication systems when they are off (or in "network standby" mode). Initial measurements indicate that energy use of smart lamps in standby mode varies from less than 0.25 W to over 2.5 W per lamp.

In this study, we present the results of laboratory research looking at active mode and standby mode energy use of 11 commercially available smart lamp models. Active mode testing includes measurements of lamp efficacy at full output as well as documenting how efficacy changes as the lamp is dimmed. Standby mode testing includes documenting the power consumption of smart lamps (and any associated control gear, such as wireless bridges) when the lamps are turned off. We explore how the design parameters of the smart lamps (e.g., Bluetooth vs. Wi-Fi, etc.) may impact standby energy use. We also discuss how much energy smart lamps can be expected to consume while in active mode and in standby mode, given typical residential usage patterns.

Introduction

In this paper, smart lamps are defined as integrated LED lamps that are wirelessly controllable, for use primarily in household applications. In the past two years these lamps have become readily available, offered by both large and small manufacturers.[1] Their appearance in the market is the result of the convergence of LED lighting and the omnipresence of wireless home networks and smart phones. Also, smart lamps typically have the ability to change colour[2] – e.g., from warm to cool colour temperature. This is referred to as "colour tunability".

Smart lamps present two significant opportunities for energy savings. They have an efficient LED light source, and are programmable by the user. This could allow the lamps, for example, to turn off and on based on preconditions such as the proximity of the user's smart phone.

However, there is an energy cost associated with the controllable element of these energy savings opportunities. Smart

1. http://www.energyrating.gov.au/blog/2014/11/25/smart-lighting-maybe-not-so-smart/

2. http://www.wsj.com/articles/light-bulbs-get-smarter-but-not-easier-1411495549

lamps consume power in order to stay connected to wireless networks. This "network standby" energy consumption is a new challenge in the effort[3] to reduce standby power consumption – efforts which should however seek not to impede the energy savings benefits afforded by controllability – known in some circles as "intelligent efficiency"[4].

This paper presents the results of laboratory testing which examined active mode and standby mode energy use of 11 commercially available smart lamp models, sourced in the US in 2014. Active mode testing includes measurements of lamp efficacy at full output as well as when the lamp is dimmed. Standby mode testing includes documenting the power consumption of smart lamps (and any associated control gear, such as wireless bridges) when the lamps are turned off. We explore how the design parameters of the smart lamps (e.g., Bluetooth vs. Wi-Fi, etc.) may impact standby energy use. We also discuss how much energy smart lamps can be expected to consume while in active mode and in standby mode, given typical residential usage patterns.

The Market (and Future Market) for Smart Lamps

The development and market entry of smart lamps has been remarkably rapid, to the degree that the widely respected McKinsey 2011 report[5] looking at the global lighting market to 2020 didn't even mention the possibility of such products. However, as noted above, smart lamps first made an appearance in the market around two years ago, with a large number of suppliers now developing families of products with various "smart" functionalities.

The appearance of smart lamps has resulted from advances in LEDs to a level of functionality acceptable to the consumer at a price they are willing to pay; combined with the increasing ubiquity of smart phones and the consumers' willingness to use them (and other mobile devices) for interaction with, and control of, devices remote from the phone itself. Further, given the flexibility of LEDs in both design and application, and the functionality that can be enabled by mobile devices, what smart lighting products may ultimately look like (or where they will be installed and what they may be used for) is currently unknown. In many respects smart lighting is at the point of smart phones ten years ago; the functional architecture and operating systems exist in various forms, but it won't be until a range of products and associated applications are brought to market that it will became clear what will be desirable to the consumer, how they will use it, and what they will be prepared to pay for. The current challenge for policy makers is to create an environment that will allow novel products to evolve and satisfy consumer needs (even if these are yet unknown), while still maintaining control of the wider impacts of the products – in the case of this paper, the issues related to energy use in their various potential operative and stand-by states.

So, how big might the issue be? The straightforward answer appears to be: no one knows. However, a 2014 report from Markets and Markets[6] estimates the global "smart lighting" market in 2020 will be worth approximately $33 billion. If the "smart lamp" itself accounts for just 10 % of this revenue, this puts sales at around the $3 billion level.[7] Assuming the price of LED technology continues to fall, and "control" applications and gear develop at a similar cost/functionality rate as other connected technologies, it is probable that smart lamps with general illumination capability will be in the order of $10/each by the end of the decade[8]. That would put sales of smart lamps at around 300 million units by 2020, or 5–10 % of the projected global lamp market. Thus, if there is a notable energy penalty associated with smart lighting, then the additional electricity demand (or sacrificed potential energy savings) could be significant for policy makers. This paper will explore the scale of this potential penalty (or sacrificed savings), and identify some of the issues that policy makers will need to address in order to manage the development of the market, even without knowing exactly what the smart lamps may look like, or what functionality they may ultimately deliver.

Lamp Communications Architecture

The most novel aspect of smart lamps is that they can communicate wirelessly. Wireless communications, at the building level, can be categorized as either Wireless Local Area Network (WLAN) or Personal Area Network (PAN). Wi-Fi is the most common form of WLAN[9] and is capable of data rates up to 600 Mbit/s with an indoor range of around 20 m. Wi-Fi devices[10] typically do not "mesh" – the end-use devices in the network do not broadcast the network in order to extend its reach – the network reach is usually only as strong as the transmission power of the Wi-Fi router.

PANs exhibit shorter ranges with lower data rates (~250 Kbit/s)[11], and include such protocols as Bluetooth, ZigBee and Z-Wave. Importantly, ZigBee (and 6LoWPAN which is based on ZigBee) can mesh (each end-use device can extend the range of the network). Hence, each lamp has the ability to extend the reach of the network. This has made ZigBee (and 6LoWPAN) a popular choice for smart lamps, presumably because existing Wi-Fi networks may not reach all areas of a house. ZigBee-based communications systems' lower power and data characteristics are well suited to intermittent data transmissions and are simpler and less expensive than Wi-Fi and Bluetooth. However, using a ZigBee-based communications system requires some kind of "bridge" which creates a link between the network

3. http://edna.iea-4e.org/about

4. http://www.aceee.org/blog/2013/10/intelligent-efficiency-it-s-smart-it-

5. Lighting the way: Perspectives on the global lighting market. McKinsey & Company, Inc. 2011.

6. Smart Lighting Market by Component & Geography – Global Forecast & Analysis to 2014–2020. Markets and Markets. May 2014.

7. The concept of "smart lighting" presented in the Markets and Markets report encompasses everything from a single lamp in a domestic environment to integrated lighting controls systems within commercial buildings. Hence the 10 % of revenue is simply an estimate of the total sales value that may be attributable to lamps which integrate some of the "smart" controls or other functionality.

8. There is speculation in some quarters that, by the end of the decade, such products will be given away free with companies gaining revenue from "knowledge" gained from consumer use (for example, smart lamps could track individuals within the home and relay information on "who is watching TV now" back to the lamp supplier, who could then sell this knowledge onto cable companies to enable delivery of personally targeted commercials in much the same way Google currently targets advertisements based on knowledge of the user).

9. http://www.wi-fi.org

10. http://en.wikipedia.org/wiki/Wi-Fi

11. http://en.wikipedia.org/wiki/ZigBee

containing the controlling application (e.g., smartphone app on Wi-Fi network) and the ZigBee lamp network. This is the reason that many smart lamp models include a bridge in the form of a separate box that is connected to the home network on one side (e.g., Wi-Fi or Ethernet connection to Wi-Fi router) and establishes the ZigBee network on the other side.

One of the smart lamp models tested for this study had the "bridge" function built into all of the lamps, rather than using a separate box for the bridge. All of the lamps were both Wi-Fi and 6LoWPAN capable. The lamp with the strongest Wi-Fi signal was automatically selected to become the single "bridge" for the other lamps. Effectively it became the master lamp and communicated with the Wi-Fi network and with the slave lamps, using 6LoWPAN. The slave lamps only used 6LoWPAN. Interestingly, this lamp model exhibited the highest standby power of all lamps tested, and standby power was similar for both master and slave lamps.

Test Procedures

Test procedures for smart lamps are not yet well defined. This is the case for luminous flux and power input (and thus efficacy) at full light output, when the lamp is dimmed or its colour changed, and for standby power usage.

Both the North American test procedure IES LM-79 and the international standard IEC 62612 require that luminous flux and power input of LED lamps be made when the lamps are not dimmed. However, these procedures do not specifically address how to test LED lamps that are colour tunable. For example, some smart lamps can be at full output at 2,700 K or 6,500 K, or even at saturated colours, and their performance can vary dramatically based on the colour setting. In order to ensure repeatable measurements that are consistent across testing laboratories, testing standards for colour tunable lamps may need to be updated to define how to adjust colour settings.

Most smart lamps offer dimming capability and, theoretically, dimming performance for smart lamps should generally be better than for standard dimmable LED lamp systems. This is because smart lamps are able to side-step the dimmer-to-lamp compatibility issues, which can produce significant negative dimming concerns for some standard LED lamps.[12] Smart lamp manufacturers are able to specify all the electronics needed to provide lamp dimming. Again, however, existing test procedures do not adequately describe how to measure dimming performance for smart lamps. They generally focus on documenting performance at full light output and do not describe how to document performance variations across the dimming curve, how far down lamps can be dimmed, or other relevant parameters.

Lastly, existing testing procedures largely do not address how to measure smart lamp standby power. IES LM-79 and IEC 62612 do not address standby power measurements at all. The US DOE has recently proposed a standby test for LED lamps that attempts to define how lamps are to be placed in standby mode by stating, "the integrated LED must be configured in standby mode by sending a signal to the integrated LED lamp instructing it to have zero light output". While this very general wording may be necessary to allow laboratory technicians the leeway to determine the appropriate manner to place smart lamps in standby mode, complications may still arise. For example, a smart lamp might have an initial standby power reading when first turned off and then may be programmed to go into a "deep sleep" with a lower standby power after a period of prolonged inactivity. Other smart lamps might establish wireless networks where the standby power of a lamp may depend on where the lamp is in the network hierarchy, as in the sample lamp with Wi-Fi *and* 6LoWPAN connectivity described above. To measure the standby power of the lamps in this study, we used the proposed US DOE method. While we did not observe scenarios such as those described in the examples above, where standby measurements varied over time or based on application, we did not explore this question deeply. Thus we cannot confirm that these or other similar issues do not affect smart lamp standby power. We recommend that test standard bodies consider the various operational modes that smart lamps are capable of operating in while in standby mode, and develop test methodologies that allow for representative and repeatable standby measurements.

Testing and Results

This section discusses the photometric and standby power test results from 11 smart lamp models tested. One sample of each model[13] was purchased from retail channels in the USA and tested by ITL Boulder, a NVLAP accredited laboratory. Lamps were initially tested at full light output in accordance with IES LM-79-08 test procedures. For lamps with colour changing capabilities, CCT was adjusted to be between 2,700 K and 3,200 K. Next, dimming performance of each lamp was documented by conducting photometric and electrical measurements when adjusting lamp control apps such that lamp outputs provided 80 %, 60 %, 40 %, and 20 % of the lamps' full light output (while holding CCT between 2,700 K and 3,200 K).[14] Lastly, the standby power of each lamp was measured by recording the lamp power when the lamp was set to the off state using the control app. For lamps that utilized an additional external bridge, the power draw of the bridge was also measured while the lamps were in standby state.

Figure 1 shows the measured luminous flux (lumens) for the 11 smart lamp models when tested at full power.[15] We note that

12. There are a wide variety of dimmers in use in residential applications and LED lamps are generally designed to work with many common dimmers. However, performance can vary widely for any given lamp-to-dimmer combination, leading to applications with lamp humming or flickering, minimized dimming range (e.g., lamp only dims to 30 %, then turns off), minimal dimming modulated (e.g., all the "dimming action" of the lamp occurs during a limited portion of the dimmers full range of settings), and other issues.

13. For one model, 2 samples were tested. This was because the first sample was found to have standby power significantly higher than other models. A second sample of this model was procured to ensure the performance of the first sample was not a result of a malfunctioning lamp. Additionally, because of the way this model establishes a mesh network, there was some thought that the first lamp on the network could have higher standby power usage than subsequent lamps, so we also wanted two samples from this model to measure whether either of the lamps in the mesh network consumed less power than the other. Ultimately, standby draw from the second lamp was found to be similar to that of the first lamp.

14. We did not conduct additional dimming tests such as measuring flicker, hum, snap-on, snap-off, etc.

15. Note that the model designations used are held constant in Figures 1–6 (e.g., model 3 shown in Figure 1 is the same lamp as model 3 in Figure 2–6) allowing the reader to track the performance of specific lamps across all the parameters we evaluated.

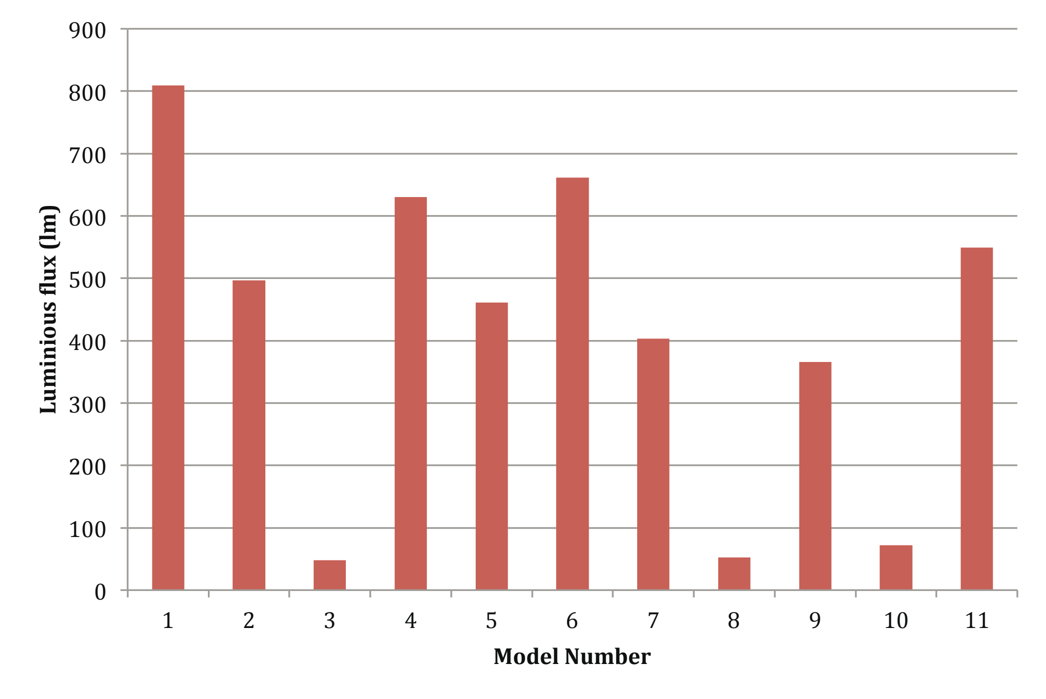

Figure 1. Measured luminous flux.

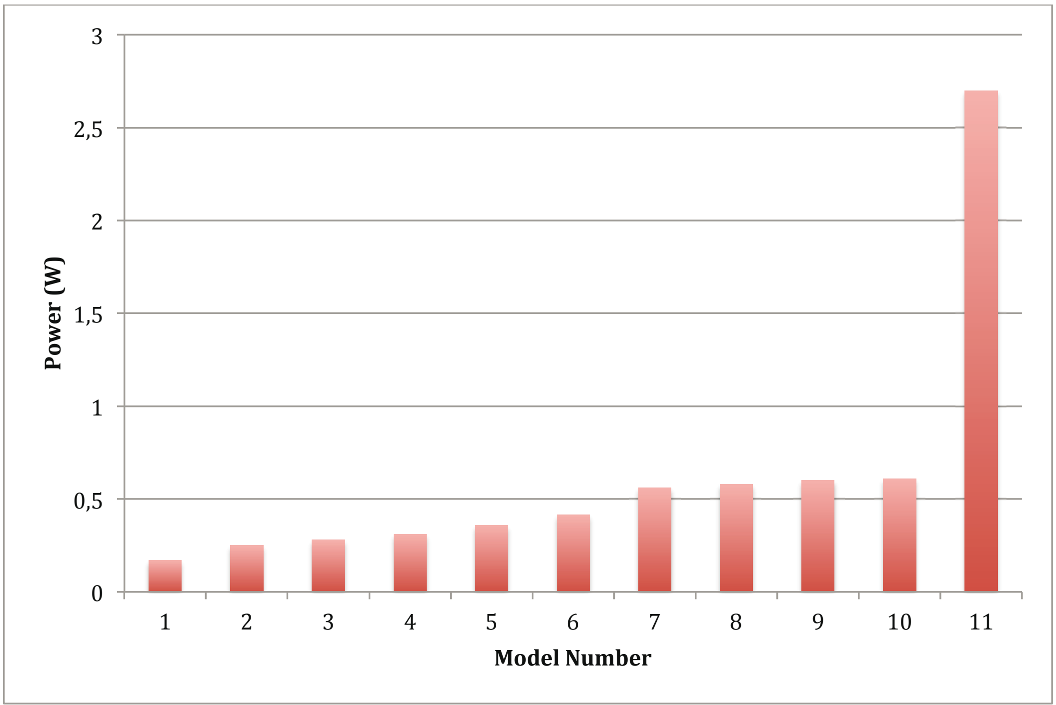

Figure 2. Standby power usage.

three of these models had lumen outputs of less than 100 lumens, suggesting that these lamps may not be appropriate for typical illumination applications.

Figure 2 presents the standby power usage found from the 11 smart lamp models tested. Standby power ranged from a low of 0.17 W up to 2.7 W. Average standby power usage was found to be 0.62 W and median standby power usage was found to be 0.42 W. Three of the 11 models (models 1, 5, and 6) had additional bridges that were found to draw between 1.72 W and 2.17 W (this additional standby draw is not represented in Figure 2).

Figure 3 shows the measured efficacy of the models tested when at full output. Efficacy values ranged from a low of 12.0 lm/W to a high of 86.9 lm/W (average = 51.2 lm/W; median = 60.0 lm/W). We note that three of the models tested had measured efficacies below 20 lm/W – values more typical from incandescent lamps than LED lamps – and that these were the same models that had luminous flux results below 100 lm.

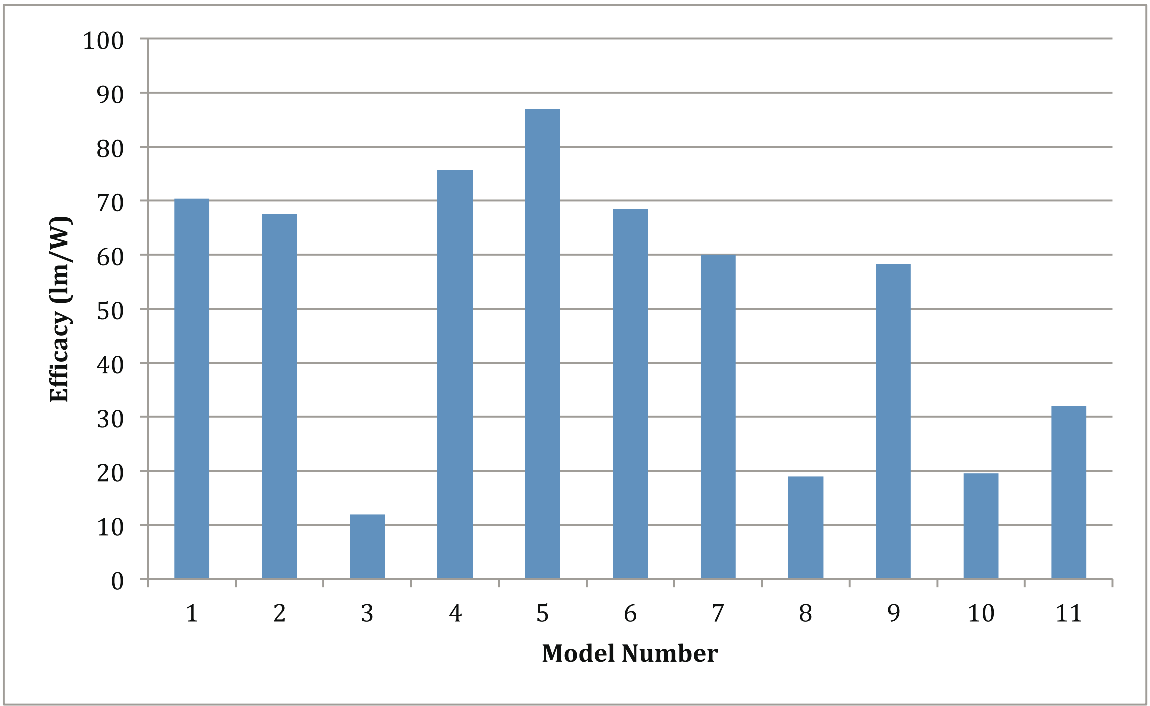

Figure 3. Efficacy at full power.

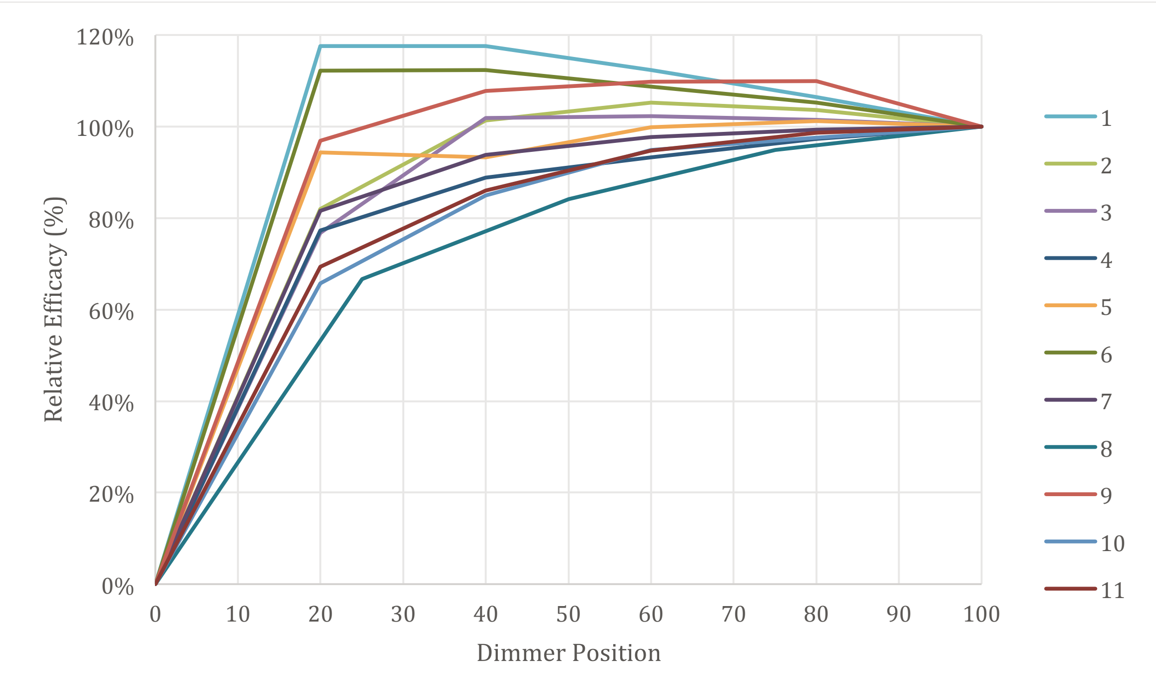

Figure 4. Efficacy as a function of dimming.

Figure 4 shows how the efficacy of each lamp was impacted by dimming. Generally speaking, the efficacy of the measured smart lamps remained steady (e.g., light output and power input drop nearly proportionally) when dimmed from 100 % down to 40 %, with modest drops in efficacy below 40 %. Several models were found to have slight increases in efficacy when initially dimmed. This may be due to decreased LED junction temperatures, which are known to positively impact LED efficacy.

Figure 5 shows how much energy (kWh) each smart lamp model would use in active mode (e.g., emitting light) and standby mode (e.g., not emitting light) annually (excluding external bridges), assuming they are in active mode 2 hours per day and in standby mode 22 hours per day[16]. Standby mode usage was

16. Not yet known is if the increased functionality of these lamps will increase net usage (e.g., lamps are used longer because they offer new features) or decreased net usage (e.g., lamps are automated or dimmed).

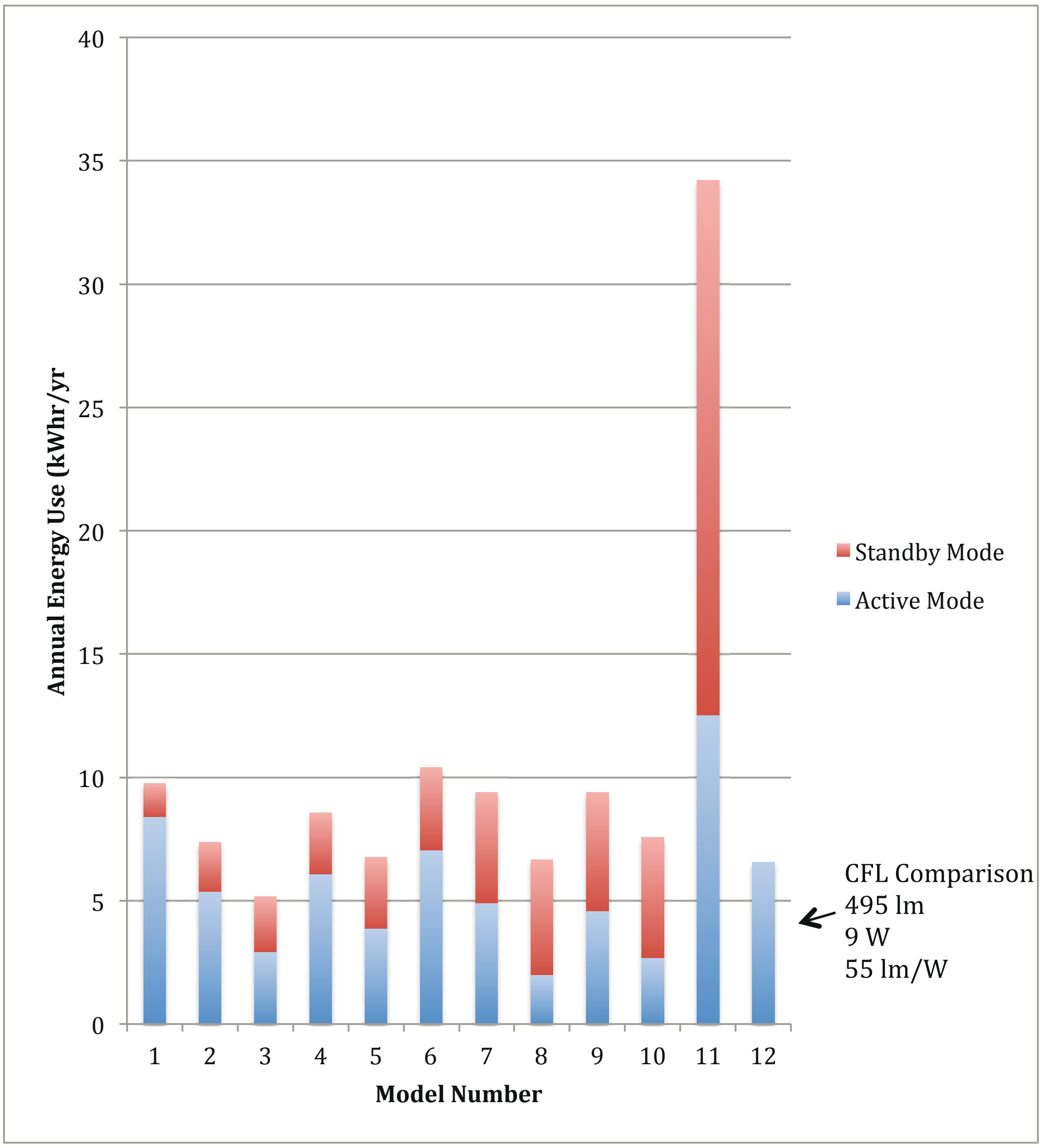

Figure 5. Annual energy usage.

found to play a significant role in overall energy use for all models. For 4 of the 11 models, standby mode was found to use more energy than active mode. These were the 3 models with very low efficacy (models 3, 8, and 10) and the 1 model with very high standby power (model 11). For comparison, a typical low-to-average efficacy CFL is shown on this graph as model 12.[17] When only considering active mode usage, only 2 of the smart lamps use more energy than the comparison CFL. But when active mode and standby mode are both considered, 10 of the 11 smart lamps use more energy than the comparison CFL.

Figure 6 shows how lamp efficacy is effectively eroded by standby power usage by introducing a new metric called "standby power corrected efficacy". This metric is calculated by multiplying the measured full power efficacy by the ratio of active mode energy use to the overall energy use (again assuming active mode usage of 2 hours per day and again excluding the power draw from external bridges[18]). For example, a lamp that has an efficacy of 60 lm/W, an active mode annual usage of 6 kWh and a standby mode annual usage of 3 kWh would have a standby power corrected efficacy of $60 \times 6 / (3 + 6) = 40$ lm/W.[19] Because efficacy is an important metric for evaluating the related efficiency of LED lamps, this metric can be helpful to determining how much overall lamp efficiency is degraded by standby power draw. On average, the full power efficacy of the 11 models tested was 51.8 lm/W while the average standby power corrected efficacy dropped to 31.9 lm/W.

17. This CFL was not tested and is a "theoretical" lamp used for comparison purposes. The lumen output of 495 was selected to provide an output that is slightly higher than the average (414 lm) and median (461 lm) outputs of the smart lamps tested. An efficacy of 55 lm/W was selected to approximate the low-to-normal efficacy of CFLs in this output range. The power of 9 W is defined by the selection of the lumen output and the efficacy values.

18. Power draw from external bridges is not included here because typically 1 bridge is used for all the smart lamps in the home and it is difficult to estimate how many smart lamps will "share" the power usage of the bridge.

19. A lamp without any standby power draw would have an active mode energy use equal to its overall energy use and thus the standby power corrected efficacy would be equal to the measured full power efficacy.

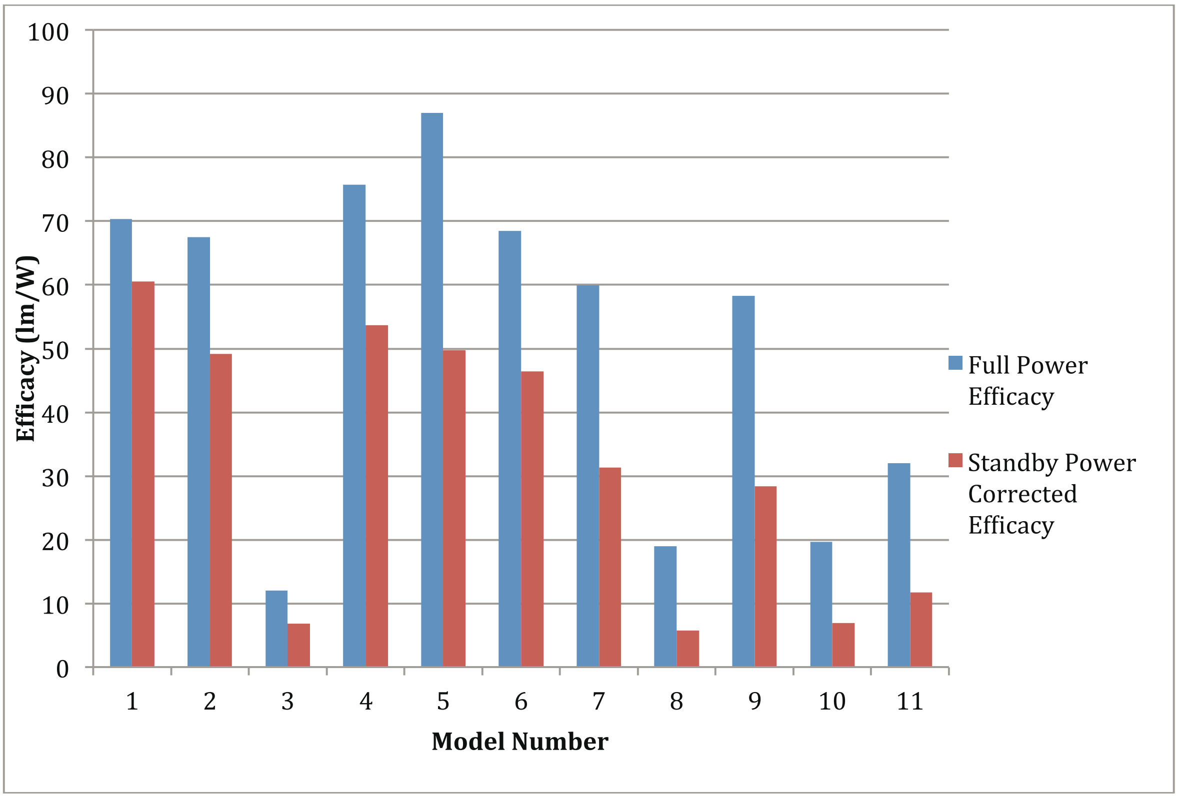

Figure 6. Standby power corrected efficacy.

Conclusions and Recommendations

Smart lamps are a rapidly growing part of the LED lamp market, which is itself growing rapidly. We estimate that smart lamps could reach annual sales of 300 million units by 2020. While the efficacy of these lamps can be expected to rise as LEDs continue to improve, the savings offered by the control features are less clear. In terms of "active-mode" usage, it is not yet clear if the added level of controls these lamps offer will result in increased usage (e.g., lamps are used longer because they offer new features such as scheduling, colour changing, etc.) or decreased usage (e.g., lamps are easier to efficiently dim or turn off). For "standby-mode" the picture is clearer – these lamps use power in ways that traditional lamps do not.

For the 11 smart lamp models tested, efficacies (at full output and ~3,000 K) ranged from 12 to 87 lm/W. The three models with measured efficacies below 20 lm/W had maximum lumen outputs of less than 100 lumens, suggesting that these lamps may not be appropriate for typical illumination applications. It is also possible that the additional energy cost imposed by the network connection (and other smart functions) of these three lamps is dominating the efficacy calculation.

Generally speaking, the efficacy of the measured smart lamps remained steady (e.g., light output and power input proportional) when dimmed from 100 % down to 40 %, with modest drops in efficacy below 40 %. Several models were found to have slight increases in efficacy when initially dimmed, which may be due to decreased LED junction temperatures, which are known to positively impact LED efficacy[20].

Standby power for the lamps tested ranged from 0.17 W to 2.7 W. Three of the eleven models had an additional bridge that was found to draw between 1.72 W and 2.17 W.

A new metric was introduced – "standby power corrected efficacy". This metric is calculated by multiplying the measured full power efficacy by the ratio of active mode energy use to the overall energy use (assuming active mode usage of 2 hours per day). Applying this metric changed the efficacy range for the lamps tested from 12–87 (conventional efficacy) to 5–60 lm/W (standby power corrected efficacy).

If the 300 million smart lamps we estimate will be sold in 2020 each have a standby power usage of 0.5 W (the average standby power we measured during our testing was 0.62 W), this represents nearly 26.5 billion kWh per year or approximately $2.65 billion per year in standby losses.

Based on the results of this study, the following recommendations are made:

- Test procedures for LED lamps should take account of dimming and colour tunability.
- Test procedures for LED lamps should take account of standby power, both of lamps and any associated "bridge."
- Energy efficiency initiatives such as MEPS and labelling should address the standby power consumed by smart lamps.

20. http://www.ledsmagazine.com/articles/print/volume-4/issue-8/features/driving-led-lamps-some-simple-design-guidelines.html