Smart Lighting & Smart Hub DIY Install: Does it Yield?

BY

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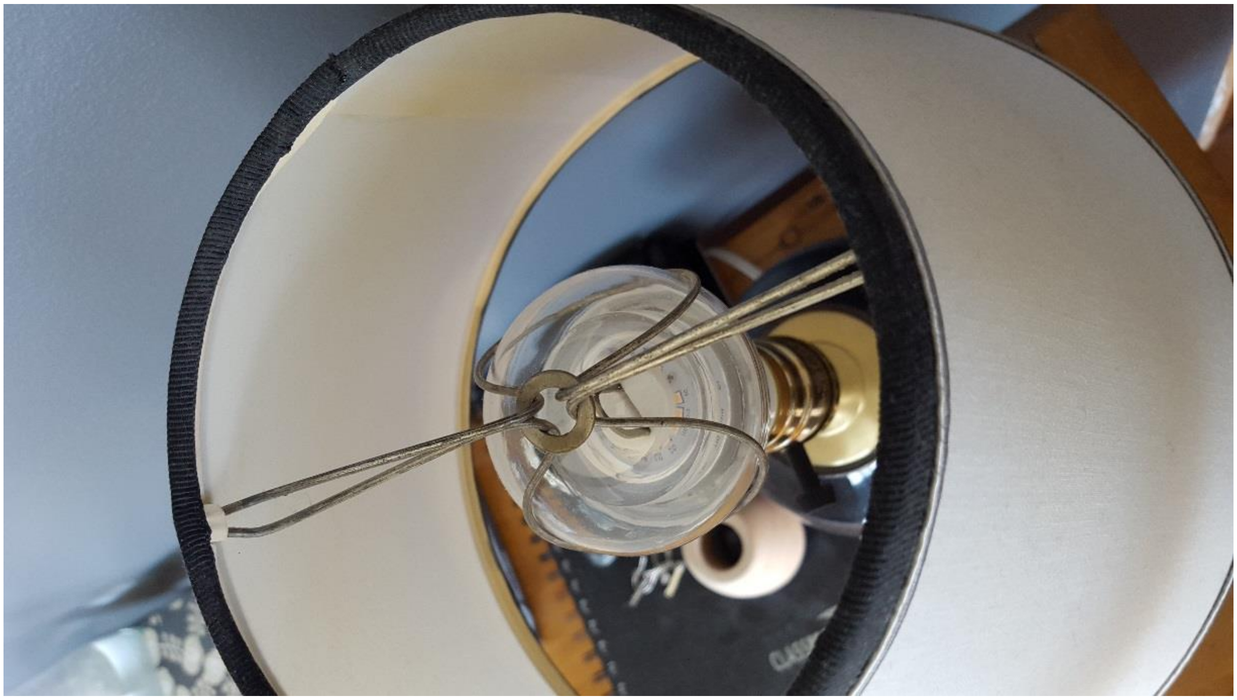

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Executive Summary

The whole-home automation market is in many ways the Wild West, with industry heavyweights jumping in and small innovators getting noticed. This market is still new, with a vast diversity of products, controlled devices, and levels of service. Although utilities might conclude from the frenetic market pace that it's better to wait until the market settles down before they get involved, a statewide energy efficiency utility, Efficiency Vermont, saw the benefit to jumping in early.

They designed a pilot to map, define, and measure the interactions of Home Energy Management System (HEMS) hubs and their connected devices. Staff screened and then selected a representative sample of homes to participate. The pilot collected data that could fill two knowledge gaps on connected devices. The first gap related to smart lighting, controlled by HEMs hubs; the study metered the lighting so that the data could inform the extent to which it might save energy under real-world uses. The study filled the second gap by cataloging a wide variety of devices used with smart outlets. To map baseline energy use, staff metered smart bulbs with light loggers and compared the data to standard, non-smart bulb energy use. The pilot also tested the products' aptitude for an energy efficiency program in the retail market by assessing the participants' "out of the box" experience with installation and use. The study asked participants to offer additional information, via two surveys during the pilot. Their responses helped inform Efficiency Vermont about the product opportunity from a program standpoint, and about challenges and advantages from using these interactive devices.

The pilot's results are in and they reveal important information about the energy savings opportunities from these devices, and how usable these devices are. Although not of a statistically significant sample size, the pilot shows especially promising results for smart bulbs' hours of use (HOU), compared to HOU for non-smart bulbs. In this small sample, we saw up to 27 percent reduction in energy use with smart bulbs. These are only preliminary indicators, and more research is needed to statistically guarantee these savings.

The pilot also showed unexpected types of use. Smart bulbs make dimming possible where none had existed before, and the results indicated that participants frequently dimmed their bulbs. In an average home, only about 10 percent of lamps are on dimmer switches. Homeowners in this pilot chose to dim their bulbs 38 percent of the time to varying light levels. This new option could yield even more efficiency potential as well as demand response opportunity. This is a big opportunity for both the lighting market and efficiency programs. We now need additional research to quantify such savings potential, and to determine how the types of homes and rooms in which these bulbs are installed might affect those savings.

There was no significant statistical difference in projected annual operating hours for smart bulbs in households that used regular automation, versus those that did not. Since these were do-it-yourself installations, with no guidance on how to schedule lighting use for greater efficiency, this finding shows that a significant opportunity exists for efficiency in scheduling.

This study also monitored and catalogued what participants plugged into their smart outlets. At one point in the study, at least 67 percent of participants recorded having some sort of lighting device plugged in (lamps, lighted ornaments / string lights, or night lights). The additional dimming capability of the smart bulb in most cases offset whatever value the on / off outlet remote control provided for these non-smart bulbs.

The pilot's results showed that users were enthusiastic about the energy and cost savings they can achieve with HEMS technology. Efficiency Vermont received a strong response to its request for participants which indicates that smart homes represent a major opportunity for efficiency programs to engage with a highly motivated market. All respondents who began the study participated fully throughout the study period.

This study represents an ideal setup for smart home technology, with major smart-home industry barriers removed through careful selection of products. Within that context we found that participants were largely able to install the smart products on their own, in an environment that mirrors a retail purchase experience. The survey responses offered a full understanding of the challenges with the equipment, particularly during installation. Despite these challenges, 47 percent of participants were surprised at how easy it was to install the product. Others were able to resolve their installation challenges, once they used the manufacturers' support tools. Efficiency Vermont staff have concluded that there is opportunity for a retail program initiative based on these results if we can prove out the savings. Nevertheless, we also recognize that further study is needed to evaluate post-installation measure life. Will consumers keep these products connected to the grid, or are they a novelty to be discarded after a few months? Overall, participants' satisfaction with smart products is high: 80 percent said they were "satisfied" or "very satisfied" with the HEMS hub; 87 percent said they were "satisfied" or "very satisfied" with smart bulbs; and 74 percent signaled similar satisfaction with the smart outlet. Customers value these products. Nearly all reported their experience with the products to be "neutral," "satisfied," or "very satisfied" at the conclusion of the study.

In terms of energy efficiency program design, we now understand the challenges with installing and using these devices. This knowledge will help us and other efficiency programs partner in new ways with manufacturers to optimize performance and functionality. In this way, we hope to increase the persistence of energy savings as well as give us new opportunities to engage with customers directly. Automation might offer additional savings, given investments in efficiency opportunities. This study investigated two different manufacturers' certified-compatible HEMS ecosystems, and found no significant difference in projected annual hours of use between the two. This suggests that efficiency programs could scale similar initiatives across manufacturers, assuming strict selection criteria for qualified products.

This study is the first to assess smart lighting and HEMS devices in real-world settings, with a nearly universal efficient application, light bulbs. Efficiency Vermont believes that the study has provided new direction for, and offers insights into, collaborating with and influencing the future state of the smart industry. Objectives might range from meeting short-term program needs, such as effective engagement with customers and achieving energy savings, to long-term influences, such as reductions in energy needed for demand response, improvements in data sharing, and integration with distributed energy resources.

Introduction

Vermont, along with much of the United States, is at a nexus between (1) the shrinking opportunity for traditional energy efficiency service delivery in appliances, lighting, and consumer electronics and (2) the emergence of the smart home.

Through increasingly sophisticated capabilities in sensing, connectivity, and computation, "smart" products and home energy management systems (HEMS)[1] can engage customers in new ways and could save energy. Another term for this market is the *Internet of Things* or *connected*, but in this report, Efficiency Vermont is using the term *smart* in its place. Despite the evolving complexity of this market, the smart home market is still in its early days. Many industry heavyweights are jumping in, and small innovators are emerging in the market with their steadily growing array of products, controlled devices, and levels of service. But without clear, leading standards and common and convenient operability, the whole-home automation market is, in many ways, the Wild West. The value a customer places on these products is not yet known. Do consumers want to buy them? Do consumers recognize their benefits, directly or indirectly? These questions cannot be answered accurately, just yet.

This frenetic market pace might make some utilities think they should wait until the market settles before they begin to invest in, or promote, smart-home technology. Efficiency Vermont, however, in 2013 saw a clear benefit to gaining an early understanding of these markets and wanted to investigate opportunities to influence how the technology worked (software design) and operated (hardware design). In 2015, it launched this research and development project to gain necessary market understanding and to test how the technology design might be improved to increase energy efficiency.

This study evaluates today's market, with a close look at current smart-home and connected electronics industry barriers to energy efficiency. It provides direction and offers insights into how the future state of the smart industry can be influenced to better coordinate with the objectives of energy efficiency programs. These objectives might range from short-term needs, such as customer engagement and energy savings, to longer-term interests, such as demand response, data-sharing, and integration with distributed energy resources.

The volume of connected products entering the market has been explosive, but the market remains young, and many key barriers remain. In recognition of the potential opportunities for market

[1] For ease of reference, Efficiency Vermont uses the term *HEMS* throughout this report, even though the industry uses more customer-centric terms, *smart hub* or *whole-home automation*.

stabilization—common communication standards,[2] product costs,[3] and vendor stability[4]—Efficiency Vermont studied products for which these factors are relatively minor. We reasoned that this is the direction in which the market will naturally mature as it evolves; by removing these barriers, we ensured that our findings will remain relevant in the future. Further, this study was among the first to assess the current connected market's suitability for an efficiency program's measure offering based on the dynamics of the retail channel. It looked at the relevant questions:

- How do current industry barriers affect future calculations for measure life and persistence of energy savings?
- Can consumers (or in the case of this study, its participants) effectively self-install these products, or will they be returned to the store?
- Do smart lighting and smart outlets represent a novelty or an opportunity to optimize performance?
- How well do these products work together, and what is the likelihood that this product / manufacturer mix will persist in market, after it "naturally" narrows to the successful products?
- What energy savings opportunities are available in today's smart home?
- Do these smart products use less or more energy than their non-"smart" alternatives?

With these questions in mind, Efficiency Vermont mapped, defined, and measured the interactions of HEMS hubs and their connected devices. Efficiency Vermont primarily addressed smart lighting and smart outlets, since they represent two of the lowest-cost entry points to the market and do not require professional installation. Further, LED lighting traditionally offers significant energy savings, and the potential for smart lighting savings is a common question that, to date, has remained unanswered.

Working with 15 study homes in Vermont, this pilot tested the smart products' potential for an effective Efficiency Vermont initiative operating in the retail market. The study assessed the participants' "out of the box" experience with installation and use. Participants answered two surveys throughout the pilot, providing critical information about the opportunity offered by the product and about challenges relating to the interactive character of the products. This pilot yielded important data about savings opportunities and the usability of these devices. The information will allow Efficiency Vermont to have constructive conversations with manufacturers about suggested changes to the products. Overall, the results of this pilot bring energy efficiency programs one step closer to having a key role in smart homes.

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[2] At the time of this study, there was significant collaboration among industry players, including major manufacturers and service providers, in adopting and conforming to standard connectivity protocols.

[3] Although hardware costs have fallen precipitously in recent years, widespread adoption of the technologies remains elusive. Without economies of scale in place, product and service costs are likely to remain where they are now—still largely beyond the reach of average consumers.

[4] Enabled by relatively low barriers to entry, and the realities of marketplace immaturity, the proliferation of start-ups and new product lines battling for market share and "mindshare" do not create much consumer confidence in the long-term viability of most devices and companies.

Study Approach

METHODS

The Efficiency Vermont Residential Smart Home Study tested the benefits of a new type of light bulb controlled by a HEMS that can communicate over wireless Internet connections. The communication capability could make new energy savings possible. The study collected and analyzed information regarding lighting settings and the length of time that lighting is on in Vermont homes, both for smart lighting and non-smart lighting products. The study also metered the HEMS device and noted how participants used the HEMS hub and smart outlets.

OBJECTIVES

This study measured the energy savings potential of these light bulbs and the HEMS hub, with the dual purpose of evaluating ways in which the products are being used, and of exploring how the data communicated by these devices can inform consumers' energy efficiency decisions.

The primary objectives were to:

- Map, define, and measure the interactions, to the extent possible, of HEMS and their connected devices.
- Map the baseline energy use of smart lighting controlled by HEMS.
- Catalogue consumer use of smart outlets.

A corollary objective was to understand the consumer experience with set-up, engagement, and use of HEMS devices.

Overview

PROGRAM / PILOT DESIGN

This pilot set out to assess the do-it-yourself (DIY) nature of HEMS hubs, smart lighting, and smart power outlets. Efficiency Vermont sent participants products without explicit instructions for set-up or use of the products. This approach thus mimicked the off-the-shelf experience most customers would likely have, had they purchased these products from a traditional retail channel, including the original packaging. To ensure that installation of products was not a major barrier to collecting accurate data, however, the study mapped three steps to the process.

1. First, participants attempted to install the products on their own.

2. Second, metering staff verified or, in some cases, adjusted the installation during an initial visit, to ensure basic functionality. Basic functionality for our purposes meant that the smart bulb was connected to the HEMS hub, and the smart outlet was connected to the HEMS hub, with all products controllable via the participant's smart phone application (app). Efficiency Vermont did not assist participants with any advanced functionality such as scheduling or If This Then That (IFTTT) conditions. Participants then used the products over a 3-month period. At the initial visit to assess installation, Efficiency Vermont metering staff also set up Light Loggers (HOBO Pendant Temp/Light UA-002-64) to record when the light bulbs were on, measuring lumen output. In the control scenario, staff provided participants with 5 smart LED bulbs and 5 regular LED bulbs. In addition, participants received smart outlets and recorded which devices they plugged into the smart outlet, at three different times throughout study.

Figure 1. HOBO light logger.

3. Third, Efficiency Vermont selected two manufacturers' HEMs hubs to assess how different connected setups might affect product installation, user experience—and, ultimately, energy use. Eight homes received one HEMS ecosystem, and seven homes received the other manufacturer's system. Staff selected the HEMS ecosystems according to the following criteria.

PRODUCT SELECTION

The nascent smart industry still has growing pains, which are expected to resolve over the coming years as the industry matures. Some of these problems represent a major barrier to the success of a retail channel program measure. We addressed this barrier through careful product selection.

Communication Standards and Compatibility

Communication protocol standards and compatibility represent two separate challenges. Communication is the ability for these devices to speak the same language or get to the same cloud platform in order to possibly interact (via ZigBee, Z-Wave, Wi-Fi, Bluetooth, etc.) but that isn't enough to ensure *compatibility*. That is another hurdle which requires either open platforms or strategic partnerships between manufacturers. A report by Northeast Energy Efficiency Partnerships (NEEP) indicates that there is no preferred standard for communication protocols in the smart / connected market. Nevertheless, manufacturers continue to design and launch many new devices, without a consistent, proven communication platform, nor clear compatibility with other devices in the market. This, the report concludes, has resulted in market confusion and fragmentation.[5] Although many initiatives on communication standards are under way, no one expects the market to concur on a

[5] Opportunities for Home Energy Management Systems (HEMS) in Advancing Residential Energy Efficiency Programs. NEEP, August 2015.

standard until at least 2017, if not 2018. In the interim, the risk of product returns to the store or other forms of consumer rejection that would mean early removal from the grid, remains high. With that concern is a further concern about the possible effects on measure life evaluations and persistence of energy savings. To mitigate the compatibility challenge, we therefore selected products that were certified compatible. This approach both ensured that we would receive valid and reliable product data, and offered an accurate reflection on what the market might look like in the coming years when there is agreement on a communication standard.

Market Uncertainty

The smart home market is undoubtedly in a technology bubble, with bullish technology forecasts indicating huge market growth. This growth will likely be seen in the number of connected devices and in global market value in the next several years. Start-up companies are flooding the national market—from 63 smart home start-ups in May 2013[6] to nearly 2,400 companies in early July 2016.[7] Not unexpectedly, the Internet of Things is also listed at the top of Gartner's 2015 Hype Cycle for Emerging Technologies[8]. Although it is likely not a true technology bubble (investors are not pervasively propping up the market), the market will undoubtedly begin to constrict as products fail and their manufacturers fall by the wayside in the future. Efficiency program administrators must consider the effects on measure life and persistence of energy savings when the market constricts and early products / startups / companies disappear. For that reason, Efficiency Vermont selected products from established HEMS hub manufacturers that had many products available, and which were certified compatible. We also chose smart-lighting manufacturers who certified their products as compatible to work with a few control hub systems. If efficiency programs are to apply incentive dollars toward smart products, it would be prudent to safeguard energy savings by ensuring that qualified products can survive the bubble burst.

Threshold for Associated Costs

Homeowners who have considered shifting to smart-home technology will quickly see how the product costs (both required and optional) can add up. As it seeks to create new value and benefits, the connected industry has yet to shake out what the consumer's pain threshold is for the smart home and its associated costs. For example, in an ideal, fully smart lighting setup, the required cost of the product (smart light bulb) is likely then to require the HEMS hub or bridge, and optional costs for a subscription service, smart wall switches, and geolocator beacons. Efficiency Vermont used the lowest possible entry point to the market, without compromising quality and functionality. For that reason, product selection

[6] Sun, Leo. "Apple's Wozniak sees Internet of Things Bubble." *USA Today*. June 12, 2015.
[7] AngelList Market: Internet of Things Startups, *https://angel.co/internet-of-things*
[8] *Gartner's 2015 Hype Cycle for Emerging Technologies Identifies the Computing Innovations That Organizations Should Monitor.* 2015. http://www.gartner.com/newsroom/id/3114217

consisted of a smart bulb, paired with a HEMS hub only, without any peripherals, extra add-ons or other required costs.

Since the DIY element was important for this study, staff considered only products that were already commercially available (some new to market smart bulbs do not require a hub). We realized that would limit the number of viable products for this project, but wanted to start from the basic premise that customers could easily pick up these products at a local store and attempt to install them on their own. Contractor-installed, service provider-based products, or more innovative technological solutions were beyond the study's scope. They would still merit further research. Since all of the products considered for this pilot were relatively new to the market, user and product reviews were critical to the decision-making on products selected for the study.

Product selection came down largely to (1) the total product cost (for the bulb, gateway / bridge, any additional costs, etc.); (2) the HEMS hub manufacturers that represented the most certified smart lighting interoperability, with optional add-ons of non-lighting products; and (3) which products should meet the new upcoming smart ENERGY STAR requirements, including drawing acceptable amounts of standby power. The products chosen were the Samsung SmartThings Hub and the Wink Hub.

Efficiency Vermont selected the A-Style bulb for the smart light bulb, because it is the most common variety. Staff chose the GE Link bulb (with the Wink Hub), and the Cree Smart Bulb (with the Samsung SmartThings Hub), because they met the certification and compatibility criteria and were the lowest-cost entry point for consumers. These products were commercially available at the time; newer iterations use advanced functionality, one facet of which allows for use without a hub. Other corollary considerations that were assessed, but ultimately not deciding factors included: lumens, watts, color temperature, dimmable range, lifespan, and warranty.

For the smart outlet, we selected the only removable outlet certified to work with Wink, the Leviton DZC Plug-In Appliance Module; and the Samsung SmartThings Outlet for the Samsung SmartThings Hub.

PARTICIPANT SELECTION

The study openly recruited Vermonters according to several qualifying criteria, advertising through Facebook and the online neighborhood forum, Front Porch Forum. That organization sends daily e-mail postings from other people in the participant's town or city (users often post goods for sale, lost-and-found notices, recommended local services, and discuss community announcements and concerns). Efficiency Vermont received an overwhelming response to the open recruitment call (244 respondents in 5 days), indicating that customers have quite a bit of interest in the smart home industry and may represent an opportunity for utility engagement.

Participant Qualifying Criteria, Survey 1:

- Must live within 30 minutes of Burlington, but not within the city itself (for keeping within a tight budget for metering staff time to visit)

- Must have a “smart ready” home (Wi-Fi enabled, with a smart phone)
- Must have a threshold number of available sockets for the study

With a target sample size of 15 participant homes, study staff asked potential participants to undergo a second screening effort to identify and ensure the best possible sample group of homes. The resulting study sample reflected a wide range of conditions related to number of occupants, number of weekday hours spent at home, and square footage of the home. Efficiency Vermont also tried to balance the percentage of wall space devoted to windows (which would affect hours of use), and the self-reported tech-savviness of the participants.

Criterion 1: Targeted census of the number of Vermont occupants[9]

- 27% of participants in single-occupant homes
- 25% of participants in 2-person homes
- 48% of participants in families

Actual occupancy achieved in the sample:

- 13% of participants in single-occupant homes
- 40% of participants in 2-person homes
- 47% of participants in families

Efficiency Vermont also assessed the amount of time participants spent at home on a weekday, and obtained a representative sample of those who worked 9-5 jobs, remained at home or worked from home, or represented some variation in between.

Criterion 2: Number of weekday hours at home[10]

- 39% of participants worked 9:00 a.m. to 5:00 p.m.
- 20% occupied the home between 9:00 and 5:00
- 41% spent 1 to 4 hours at home between 9:00 and 5:00

Efficiency Vermont attempted to ensure that the participant sample reflected a similar makeup to the square footage of Vermont homes.[11] However, participants in larger homes in this study were underrepresented. None of the potential participants self-reported square footage in the 3,001 – 4,000 square feet range, which should have comprised 13 percent of the sample. Only 4 participants self-

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[9] 2010 US Census Data (2-person homes assumed based on % of families and % of single-occupant homes)
[10] Department of Labor American Time Use Survey 2011. Average % of working 9-5 by hour x % of employed and Rapoza, K. One in Five Americans Work From Home: http://www.forbes.com/sites/kenrapoza/2013/02/18/one-in-five-americans-work-from-home-numbers-seen-rising-over-60/ (% who spend 1-4 hours home between 9-5 assumed).
[11] Vermont Single Family Existing Homes Onsite Database, 10-26-12.

reported living in homes in the 2,001 – 3,000 square feet range; we were hoping for 5. For that reason, participants in the 1,001 – 2,000 square feet range were overrepresented by 28 percent.

Participants by and large used Apple devices to interact with the connected products. Only 13 percent reported using an Android device with the smart lighting products. We asked the primary user of the smart home devices to complete the second survey regarding their experience with the products. Of the primary users, 60 percent were female, 40 percent were male; 7 percent identified themselves as between 18 and 24, 27 percent between 25 and 34, 53 percent between 35 and 44, and 13 percent as between 55 and 64.

None of the potential participants self-reported their technology skills as below average potentially because folks interested in smart homes are likely to be more technologically savvy and part of the early majority. This is not representative of the larger population; this proportion likely affected the results of the self-installation assessment.

PRODUCT INSTALLATION

Efficiency Vermont mailed the products to the participants at least two weeks in advance of the initial in-home visit with staff, and asked that they install products by the time of their scheduled visit. Efficiency Vermont mailed each participant one HEMS hub, five smart light bulbs, and one smart outlet. We asked that participants install all smart bulbs in either the living room or kitchen, because those typically are the highest hours-of-use (HOU) rooms in the home.[12] Despite our initial participant screening requiring participants to ensure they had enough appropriate sockets in the living room or kitchen, some participants had incorrect fixture types or bases in those rooms. For that reason, we had to install a few smart bulbs outside the highest HOU rooms, installing smart bulbs in the next-highest-use areas / fixtures in the home. In any future studies, screening should offer visuals of socket or fixture types that are ineligible, such as pin-based bulbs or linear tubes. After participants installed the products, staff asked them to complete a short online survey regarding their installation experience. Results of the first survey are outlined in **Table 1**.

Table 1. Response to survey question: For this study, how many of each bulb style did you replace?

Bulb Style	Number of Bulbs Replaced	Proportion of Bulb Style Replaced
Halogens	1	1%
Incandescents	19	25%
CFLs	37	50%
LEDs	16	21%
No response recorded	2	3%

[12] NMR Group, Inc., *Northeast Residential Lighting Hours-of-Use Study*. 2014.

When asked why they participated in the smart lighting study, participants primarily reported that they had an interest in saving energy or in energy efficiency, followed by a general interest in new technology, learning more about their home energy use, features such as remote lighting control and safety / security while on vacation, and the environment or their carbon footprint.

All respondents reported being initially pleased with the quality of the newly installed smart bulbs. Some participants noted improvements over their previous lighting technology, such as a warmer color than replaced CFLs, or an “instant on” response to applying the switch. Select comments:

- I especially like that I can change the wattage to exactly what one needs without changing the bulb, ambient light to reading light to ...
- I was actually impressed with the quality because I was not sure how well they would work.
- One participant who replaced a combination of incandescents, CFLs, and LEDs said the lighting quality was “very good. I can't tell the difference between these and my previous bulbs.”

When asked which features of the smart lighting products they were most excited about, participants reported, in order of importance:

1. Remote control
2. Dimming fixtures that were not previously dimmable
3. Controlling only one bulb on a circuit with other lights
4. Scheduling automatic on / off when arriving home late or during Daylight Savings Time
5. Correcting for inopportune switch placement
6. Ambient lighting (dimming scenes)

A few respondents noted that smart lighting would enable them to mitigate light switches that were in challenging locations, such as not having a switch near their entrance, or:

> It is exciting to know that I can turn off a light with my phone to leave the room without having to cross the room to turn off the switch and then walk through a dark room to leave it. Our cats will certainly appreciate not being stepped on!

Efficiency Vermont also asked participants to assess on a scale of 0 to 10 how difficult it was to connect either the hub to their network, download the app, or connect their smart bulbs and, separately, smart outlet to their phone / app. As expected, given the ubiquity of apps, participants on average reported the app download to be the easiest part of the process. Beyond that, participants on average found the smart bulb installation to be the most difficult step, followed by the installation of the power outlet and the hub, as shown in **Table 2**.

Table 2. Participants' self-assessment of the difficulty of DIY installation experience

Product	Difficulty Rating (on a scale of 0 [very easy] to 10 [very difficult])														
	Participant Identifier														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Hub to network	7	0	3	1	1	7	5	1	0	5	0	0	6	1	5
Downloading app to phone	0	0	1	0	0	2	0	1	0	1	0	1	2	0	1
Smart bulbs to phone / app	3	0	3	0	0	7	0	7	0	9	5	4	6	4	5
Smart outlet to phone / app	5	0	10	0	7	2	0	7	0	0	0	2	3	2	5

Overall, the participants' self-assessment of the difficulty of their installation experience had a wide range but tended to either weigh toward easy or moderate depending on the stage. Because this study hopes to assess the feasibility of these products in the DIY nature, it is important to outline some of the challenges below to highlight opportunities for future efforts despite the fact that these challenges with installation experience were not skewed toward challenging experiences.

Some of the specific challenges included one participant who experienced a challenge in set-up because the manufacturer's hub (Wink) had a software / firmware update issue at the time we deployed the hubs. A few participants noted the need to reset the hub a few times during the installation process. One participant experienced Internet issues during hub installation, and was unable to determine if the cause was the hub or the household's Internet service. Comments regarding hub installation:

- It didn't connect at first; I called customer service (who was super helpful) and they had me do it again.
- Initially connected on first attempt, but then it went offline and took several attempts to re-connect even after deleting old profile. Hub needed a reset.
- App instructions were confusing.
- Hub was not immediately recognized. Also had to find a space next to the wireless router because instructions in the box said that they had to be about 7 inches from each other.

A few participants commented that product labeling hindered their installations. Two participants noted that their light bulb packaging instructed them to download one hub manufacturer's app, even though the products were compatible with the provided hub from another manufacturer. One participant observed that a tech-savvy customer would understand that the hub is the control center of the smart ecosystem, and would therefore download the appropriate hub's app; a less tech-savvy individual would have more difficulty. An example of one user's experience:

> I was confused at first because I installed the Cree lightbulbs first, and the packaging said to download the Wink app, which I did, but then it did not appear to be compatible with the Samsung SmartThings Hub and said that I needed a Wink Hub. The installation of the Samsung SmartThings Hub itself was very easy, but the compatibility issue was what made it difficult.

The naming and labeling of one of the smart outlets confused a few participants:

> I'm not sure what it's for... so I didn't install it.

> I didn't understand what the purpose of the appliance module was or how to use it. I had to look it up on online and it still took a ton of time to get all set up.

Among other smart outlet installation challenges, participants noted that it took a few tries to get it right. Some said they had to unplug and re-plug it a couple of times, or reset the hub a few times before it found the outlet. Others found some ambiguity with the process, noting that it wasn't intuitive to have to press a button before installing the smart outlet in the wall outlet, or that the instructions around pressing the button weren't clear. A few of the participants explicitly noted that although they had challenges, once they got it, it was easy.

Of the participants who experienced problems when installing the smart bulbs, a few said that some of the five bulbs were easy and quick, whereas one or more of the five would not connect, or took a long time to connect. When one or more bulbs did not connect, participants reset the hub or bulb (sometimes a few times); another contacted customer support via live chat, noting that it fixed their problem and the agent was very knowledgeable. Other participants observed that the system did not recognize some bulbs right away, and that it was difficult to understand what was causing the non-connection.

Efficiency Vermont asked the participants about what manufacturer support services they used when installing their smart product suite. The response: 25 percent of one manufacturer's participants and 14 percent of the other's reported not needing to use any in-app support features. When participants did use in-app support features, the vast majority (75 percent and 86 percent) of participants used the highest / most visible level of support (*Instruction Manual* or *Quick Start Guide*).

Fewer SmartThings participants used the other in-app support features generally, such as product support videos or support articles. One SmartThings participant noted that the product in the support video did not match her model, so she had to double-check that she was using the right one. One participant who used support features noted that they had great customer service.

Participants across the board used more varied Wink in-app support features, a trend that was likely due to the concurrent firmware update. More participants used the call support, chat with support, and e-mail support features than SmartThings users, noting that Wink support was very friendly. One family had to ship its hub back to Wink for a reset, because of the update, but Wink made the process very easy and sent a prepaid return box. Another participant noted that the *Step-by-Step Instructions* and *Quick Start Guide* were both very easy to understand. Participants generally agreed that in-app support was good, and that it told them how to reset the hub and lightbulbs, and suggested renaming the appliance module to make it easy to identify.

Very few participants sought support from channels other than the in-app support. Twenty percent sought help from a friend or family member, and 20 percent reported seeking help from the manufacturer's website. One participant reported seeking help from youtube.com.

When asked what additional information would have been helpful during the installation process, 33 percent of participants reported that they had everything they needed to install. Another 27 percent reported confusion between printed instructions on the product and app instructions, or confusion between product families as to what instructions were listed on the product packaging. For example, the bulb packaging might contain printed instructions for downloading one app, whereas the hub packaging might instruct the user to download a different app. This conflicting information was confusing to participants not intimately acquainted with the smart home setup, or with technology generally. Thirteen percent of participants said they would have found use cases helpful, such as how to use the products, or advantages of the products. Another 13 percent reported that it would have been helpful to understand what the appliance module actually is. One participant suggested the manufacturer should indicate the estimated time to take to install everything; another could not locate the in-app troubleshooting guide, and would have liked to have referred to one.

Despite reported challenges with installation, when asked what about the installation process surprised them the most, 47% of respondents answered that they were surprised at how easy it was. Other participants reported being surprised by:

- "The time it all took – the Wink app is very good with telling you what to expect & troubleshoot."
- "That I wasn't able to do it easily, as I'm usually somewhat tech-savvy."
- "Bulbs didn't work. Couldn't access Smart Home via a website."
- "That I could invite another person to join the hub via their e-mail address; that products made by different companies could work so well together; and that the smart outlet doesn't seem very useful, now that I could just have smart bulbs!"

Product / User Experience

In the second survey effort, Efficiency Vermont asked participants whether they regularly automated control of either their smart lighting or smart outlet. Fifty-three percent reported regularly using either the **Modes** or **Shortcuts** feature on a regular basis to control multiple products at once. Surprisingly, only 20 percent reported regularly using **Routines** or **Robots** to automate certain processes in their homes. Of these, participants scheduled lights on / off, dimmed, or controlled the smart outlet in the following ways:

- We automated our air conditioner to go on before we arrived home, and used the app to turn it off, if we left and forgot to turn it off.
- Bath Relax[13] lowered the lights in the bathroom for a dim, calming bath experience; controlled by button. **Good Morning**, scheduled to turn on at 5:40 am. Dim at first, then turned up as we woke up. **Good Night** turned all lights off. **Goodbye** turned all lights off. **I'm Back** turned a few specific lights on to a bright light setting. **Relax** dimmed all of the lights to a very low setting.
- I used four main routines on the SmartThings app: **Good Morning, Good Night, Goodbye,** and **I'm Back. Good Morning** made only the two kitchen smart bulbs turn on, **Good Night** turned off all of the products we had, **Goodbye** did the same, and **I'm Back** turned on the two kitchen lights and one lamp in the living room. The **Routines** feature in the app was very helpful when I was trying to manage multiple lights at once.

Forty percent said they had smart bulbs programmed to turn on / off automatically in their homes, which could be explained by the fact that some participants noted using customized settings rather than **Routines** or **Robots** to control their bulbs.

When asked at the end of the study to reflect on their experience with the smart-home products, none of the participants reported being dissatisfied or very dissatisfied with any of the HEMS hubs or smart bulbs. Additionally, only one participant reported being dissatisfied with the smart outlet experience, as shown in **Table 3**. See **Improving the User Experience.**

Table 3. Participants' satisfaction with overall smart product experience

Product	Satisfaction Level with Product Experience				
	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
HEMS hub	-	-	20%	33%	47%
Smart bulbs	-	-	13%	40%	47%
Smart outlet	-	6%	20%	47%	27%

Efficiency Vermont disclosed the cost of each product, and asked participants at the conclusion of the study if they would recommend the smart-home products to a friend. Nearly half (47 percent) said they would recommend the entire smart-home suite (hub, bulbs, outlet) to a friend. Beyond that, 73 percent would recommend, at minimum, the HEMS hub and smart-bulb setup. These data are presented in **Table 4**.

Only one participant would not recommend a single smart product (hub, bulbs, outlet) to a friend. This participant felt that the smart products required putting a lot of thought and time into the use case of

[13] This was in only one of the participant's homes, which was very small and did not have enough sockets in the kitchen or living room for smart bulbs.

avoiding flipping a switch because they did not have a better use case, but indicated that now that the study was over, exterior lighting might be a better use case.

Table 4. Response to the question: "Given this price point, would you recommend?"

Product	Would you recommend this product to a friend?	
	Yes	No
HEMS hub	80%	20%
Smart bulbs	87%	13%
Smart outlet	60%	40%

When asked why they wouldn't recommend a given smart-home product, three participants noted that the cost / benefit analysis for the smart outlet just didn't add up. Another indicated that the greatest use for the smart outlet was lighting, but that the outlet doesn't help with dimming (as the smart bulbs do), it was complicated to set up, and it made a clicking sound when turned on or off. One participant noted that it was nice to be able to adjust bulbs separately from others on a single switch.

Methods

LIGHT LEVEL LOGGER METHOD AND ANALYSIS

A light level logger (Onset HOBO UA-002-64) accompanied each light bulb, recording light levels of each bulb when on, off, or dimmed. Light level loggers measure light intensity in lumens per square foot, every two minutes. Efficiency Vermont subjectively determined an on / off threshold for each logger, to compute run-hours during the study period. Staff calculated daily run-time and estimated annual run-time. The Vermont Energy Investment Corporation, the company administering Efficiency Vermont, built a software interface, the Lighting Analysis Tool, to streamline and standardize this process for light level logger data analysis. Staff used participant survey data and meter data to project annual operating hours, categorized first into subsets of types of bulbs—smart, non-smart, or a combined category containing all bulbs—and then subcategorized on ancillary variables, as shown in **Table 5.**

Table 5. Ancillary variables, derived from survey questions

Ancillary Variable Name	Survey Question	Values
Room type	--	• Bathroom • Bedroom • Dining room • Family room • Hall • Kitchen • Laundry room

		• Living room • Mudroom • Office • Stairwell
Percentage window composition of exterior wall	Approximately, what percentage of the exterior wall space in your living room and kitchen consists of windows or glass doors?	• 0-25% • 26-50% • 51-75%
Number of occupied 9-5 hours	On a typical weekday, how many hours is your home occupied between 9 a.m. through 5 p.m.?	• 0 • 1-4 • 5-8
Smart package type	--	Samsung SmartThings, Wink
Regular use of automation	Throughout a majority of the study, did you have any of the smart bulbs programmed to automatically turn on / off in your home?	• Yes • No

Metering staff recorded the room type and other values from their installation notes for the households. From each data slice, staff calculated descriptive statistics[14] for projected annual operating hours: mean, standard deviation, minimum, 25th percentile, 50th percentile, 75th percentile, and maximum value—in addition to the count of samples informing the statistic. Using Welch's t-test, staff statistically tested comparisons between the mean projected annual operating hours of pairs of slices, deriving the points at which a statistically significant difference existed between the values.[15]

Given the values of the five ancillary variables, staff compared fourteen data slices, as shown in **Table 6.**

Table 6. Data slices used for deriving differences among values

Slice Name	Description
Kitchen	Bulb was in kitchen
Living	Bulb was in living room
Kitchen or living	Bulb was in kitchen or living room
Not kitchen or living	Bulb was neither in kitchen nor living room
0-25% windows	Bulb was in a household with 0-25% exterior wall window coverage
26-50% windows	Bulb was in a household with 26-50% exterior wall window coverage
51-75% windows	Bulb was in a household with 51-75% exterior wall window coverage
0 hours occupied	Bulb was in a household with that was occupied 0 hours of the work day
1-4 hours occupied	Bulb was in a household with that was occupied between 1 and 4 hours of the work day

[14] Descriptive statistics are numbers that summarize and describe data, such as the mean, median, standard deviation, etc.
[15] http://statistics.berkeley.edu/computing/r-t-tests

Slice Name	Description
5-8 hours occupied	Bulb was in a household with that was occupied between 5 and 8 hours of the work day
Samsung SmartThings	Bulb was in a household that received the Samsung SmartThings smart package
Wink	Bulb was in a household that received the Wink smart package
Regular automation	Bulb was in a household that regularly used bulb automation features
Not regular automation	Bulb was in a household that did not regularly use bulb automation features

These significance tests helped to assess whether observed differences between mean projected annual operating hours for different slices were likely to be true differences. We also calculated the study's mean daily hours of use for all, smart, and non-smart bulbs and compared them to the values reported by the 2014 Northeast Residential Lighting Hours-of-Use Study, which metered lights across Connecticut, Massachusetts, Rhode Island, and upstate New York.[16]

To analyze the use of dimming features on the smart bulbs, we extracted the raw metered light intensity data for each bulb, cropped it according to defined processing rules in the Lighting Analysis Tool, and scaled the data linearly to the interval [0,1], according to the maximum of each dataset. Using these transformed data, we calculated the percentage of on-time that the light intensity is above or below given thresholds, and examined descriptive statistics about the distribution of intensities across the metering period.

HEMS METER METHODS AND ANALYSIS

The HEMS hubs were also metered to better understand the baseline use case for these devices, while at minimum controlling smart lighting and a smart outlet. The HEMS hubs were plugged into an Onset HOBO Plug Load Data Logger (#UX120-018) for the duration of the study. Onset HOBO Plug Load Loggers measure electricity use at 2 minute increments. At the end of the study, the data were downloaded for the duration of the study period.

SURVEY METHODS AND ANALYSIS

Efficiency Vermont used convenience sampling to recruit 15 Vermont participant homes. We asked people interested in the study to complete two brief screening surveys. From the list of qualified respondents, Efficiency Vermont staff selected 15 participants who met the criteria described in **Participant Selection**.

[16] https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/Program-Evaluation/2014ContractorReports/2014-EMEP-Northeast-Residential-Lighting.pdf

In addition to installing smart technology and light level loggers in their homes and using the technology, participants were required to provide feedback on their experiences with smart-home technology, via two online surveys. Efficiency Vermont administered one after participants set up the equipment; the second, when participants completed the program. Staff preferred online surveys to in-person interviews because online methods encourage unbiased feedback, immediately upon reaching a project milestone. The first survey asked participants 25 questions, half of which were open-ended, as soon as they had installed their smart-home products. The questions addressed installation experience and participant expectations for smart-home technology. The second survey asked about participants' experience with the technology, with up to six open-ended questions, depending upon their responses.

The feedback was primarily qualitative, although rating questions measured key metrics, such as ease of set-up, overall satisfaction, and likelihood to recommend. Staff created cross-tabs of the dataset to examine any major differences between the different equipment types. Staff then paired the resulting in-depth qualitative findings with the data set from the light loggers to create a better understanding of the user experience.

Findings

GENERAL

Operating hours are the key attribute of energy use patterns measured by this study. Most of the installations were in kitchens and living rooms, typically the highest-use areas of the home. However, since the study prioritized installations of smart bulbs in the highest-use areas, it is hard to draw overall conclusions about the operating hours of smart versus non-smart bulbs throughout the home. When we pulled in an additional meter evaluation study for similar sockets, the findings were informative. Also, the sample sizes are too small to produce tight estimates of operating hours, so caution should be used before drawing broad conclusions from these results.

Statistically, one of the effects of small sample sizes is an increase in the risk of detecting false negative correlations—that is, that the study will not detect a difference between annual operating hours in two rooms when a difference actually exists.[17] This is measured as the statistical power of a significance test. A low statistical power reduces the chance, for example, that the study will detect a difference between two rooms; it also reduces the likelihood that any differences found to be statistically significant are true differences. Essentially, we do not assume these results are sufficiently reliable to make absolute statements.

[17] Compare with *significance level*, the probability that a difference will be detected when a difference does not exist. The significance level is related to a Type I error (the chance of false positives), whereas *statistical power* is related to a Type II error (the chance of false negatives).

To better understand the issue, we present observed effect sizes (standardized as difference of means divided by standard deviation), along with the actual number of samples available for each comparison.

SAMPLE SIZES BY ROOM TYPE

Given the small sample size, **Figure 2** shows the number of light level loggers, disaggregated by different room and bulb types. **Table 7** shows the associated numeric counts. From these data, the overwhelming majority of bulbs are concentrated in the kitchen and living room, per the study design. The number of bulbs then steeply drops off in each of the following: dining rooms, bathrooms, bedrooms, and hallways. A few additional bulbs are located in each of the remaining rooms: offices, laundry rooms, stairwells, and mudrooms.

Table 7. Number of light level loggers per room type

Room	Number of Light Level Loggers[18]		
	All Loggers	Smart Bulb Loggers	Non-Smart Bulb Loggers
Bathroom	12	3	9
Bedroom	8	2	6
Dining room	12	5	7
Hall	7	1	6
Kitchen	32	24	8
Laundry room	3	0	3
Living room	40	34	6
Mudroom	1	0	1
Office	4	3	1
Stairwell	1	0	1
Total	120	72	48

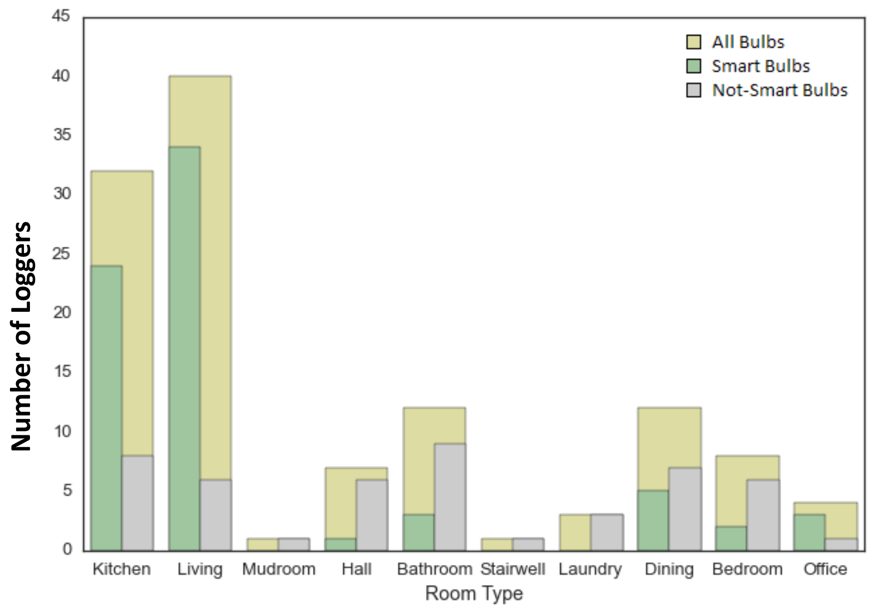

Figure 2. Bar chart: number of light level loggers per room type.

[18] One smart bulb light level logger was lost, and 2 smart bulb light level loggers were unaccounted for, resulting in 72 of the 75 expected loggers. Additionally, the 48 represented non-smart bulb light level loggers often consist of one logger representing multiple bulbs in an enclosed fixture. With the exception of a few unaccounted-for loggers, the 48 loggers represent the majority of the 75 non-smart bulbs used in the study.

PROJECTED ANNUAL OPERATING HOURS: BY BULB TYPE

This section of results considers projected annual operating hours of use on the aggregate. While smart bulbs were largely installed in the highest-use rooms in the home, non-smart bulbs were installed in a wider variety of rooms as indicated in **Figure 2** and **Table 7**. It is important to keep this in mind while reviewing the following findings so as to not draw false conclusions. **Appendix A: Distribution of Operating Hours by Room Type & Investigation of Kitchen and Living Room** and the section **Comparison of Operating Hours to Northeast Residential Lighting (NRL) Study** compares our study with a wider body of data to more accurately distinguish smart and non-smart bulb use.

The data recorded and pulled from the light level loggers show the amount of light that emanated from the bulbs in 2-minute intervals. From those intervals and light levels, we calculated a few different factors. The first is the projected overall annual run hours (not by room type or variables). **Figure 3** shows the projected annual run-hours for each bulb type. It is important to note that a larger number of smart bulbs were installed in primary living spaces and many more of the non-smart bulbs were installed in secondary sockets (see **Table 7**) and thus, not comparable. From the histograms in **Figure 3**, we see that the distribution for each type is weighted more heavily toward lower projected annual operating hours. Among both smart and non-smart bulbs, most bulbs have operating hours close to or less than 1,000 hours per year or 2.7 hours/day. Even though this study is not statistically significant, a 1,000-hour run time is less than Efficiency Vermont's current lighting TRM HOU which estimates HOU at 1200 hours annually or 3.3 hours per day.

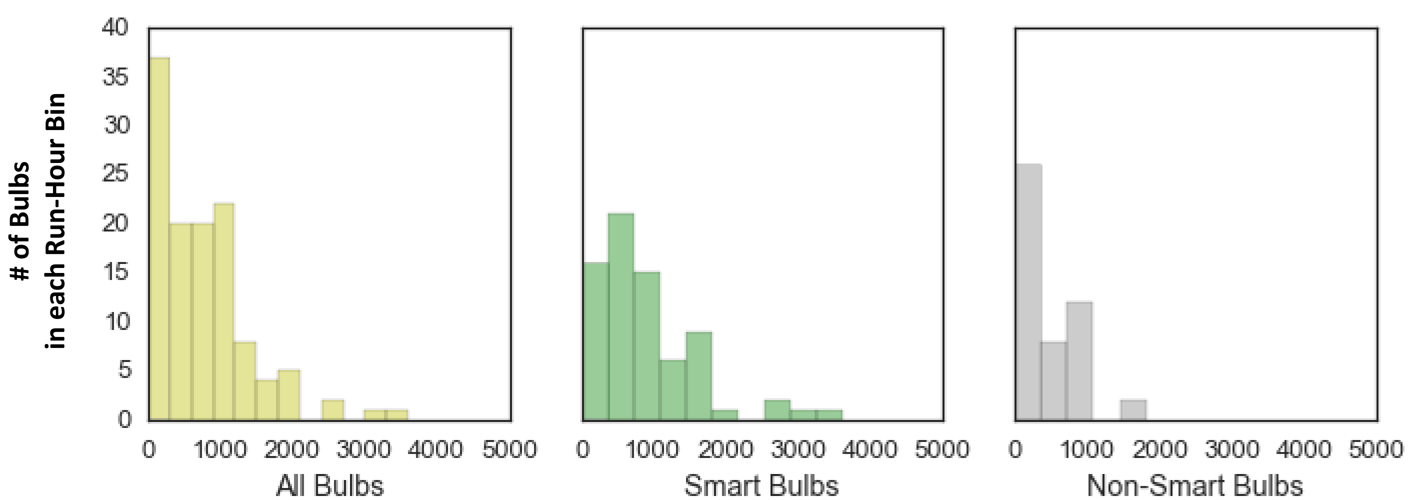

Figure 3. Projected annual operating hours, by bulb type.

Visualizing these data in another way, using a box plot (See **Figure 4**), the projected mean level of annual operating hours for smart bulbs is almost twice as that for non-smart bulbs. This is to be expected given that a larger number of smart bulbs were installed in kitchens and living rooms, with more non-smart bulbs installed in mudrooms or hallways (See **Table 7**). Because of our sample size, we are also comparing our results to a larger body of data that represents baseline non-smart bulb use at a later point in this study (see **Comparison of Operating Hours to Northeast Residential Lighting (NRL) Study**). The mean for both smart and non-smart bulb types varies greatly as shown by the size of the interquartile ranges depicted by the boxes in **Figure 4**. By the measure of 1.5x the interquartile range limit, four smart bulbs could be considered outliers when seen in the distribution of the projected annual operating hours of the other smart bulbs.

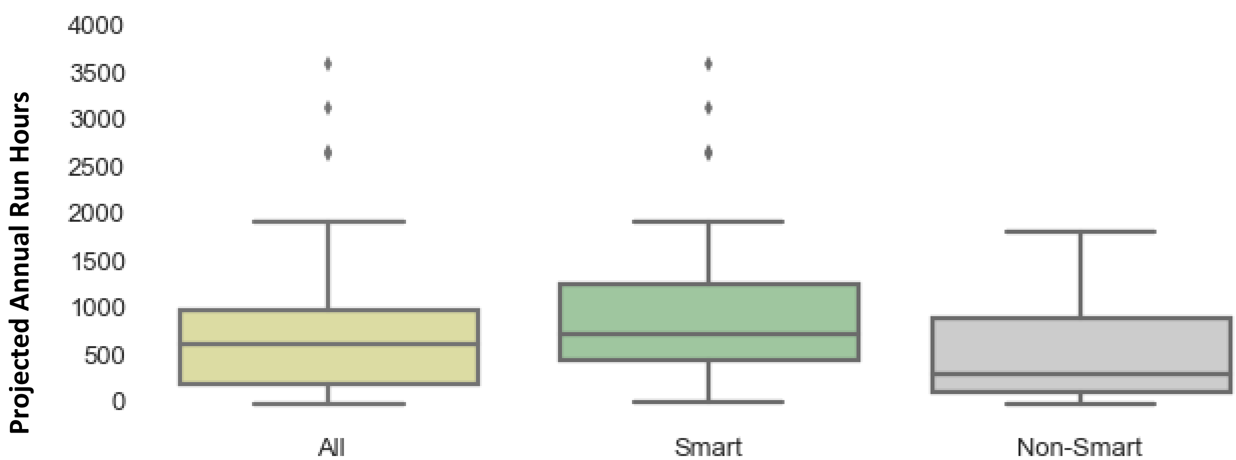

Figure 4. Means of projected annual operating hours by bulb type.

Interpretation for box plot:

- Box shows the interquartile range.
- Whiskers extend 1.5x past the low and high quartiles
- Points outside this range are outliers and shown as diamonds

Next, **Table 8** illustrates the values of the means, standard deviations, maximums, and interquartile ranges for each bulb type. We verify that the means, and the maximum projected annual operating hours for smart bulbs, are nearly twice that of non-smart bulbs. The standard deviations for projected annual operating hours are large, compared to the means for each bulb type. To compare smart bulbs with non-smart bulbs, we calculated the coefficient of variation, which is a measure for standardizing two datasets so that they can be compared to each other in ways that other measures like standard deviations cannot (for differing datasets). Due to the large size of the mean for smart bulbs, smart bulbs actually exhibit relatively less variation (cv = 0.79) than non-smart bulbs (cv =0.92). We should therefore consider smart bulbs to be less variable than non-smart bulbs. This also indicates that whereas the mean operating hours for smart bulbs are higher, there is substantial variation within each category.

Table 8. Descriptive statistics for projected annual operating hours, by bulb type

	All Bulbs	Smart Bulbs	Non-Smart Bulbs
Count	120	72	48
Mean	734.29	911.01	469.22
Std	657.90	721.63	435.46
Min	0.69	21.25	0.69
25%	204.19	452.34	125.00
50%	635.90	730.74	302.59
75%	1000.33	1258.72	905.09
Max	3602.04	3602.04	1809.19

Comparison of Operating Hours to Northeast Residential Lighting (NRL) Study

Table 9 shows mean daily hours of use (with a 90% confidence interval in parentheses) for different room types, as recorded by the Northeast Residential Lighting (NRL) Hours-of-Use Study.

Table 9. NRL study's mean daily and annual hours of use

Room Type	All Bulbs	Annual Hours of Use	Efficient	Inefficient[19]
Bedroom	2.1 (1.9, 2.3)	767	2.4 (2.2, 2.6)	1.8 (1.6, 2.0)
Bathroom	1.7 (1.5, 1.9)	621	2.1 (1.8, 2.3)	1.4 (1.1, 1.6)
Kitchen	4.1 (3.9, 4.3)	1,497	4.3 (4.1, 4.6)	3.7 (3.4, 4.0)
Living space	3.3 (3.1, 3.6)	1,205	3.6 (3.4, 3.9)	3.0 (2.8, 3.2)
Dining room	2.8 (2.5, 3.1)	1,022	3.1 (2.8, 3.5)	2.5 (2.2, 2.8)
Exterior	5.6 (5.3, 5.9)	2,044	6.0 (5.6, 6.3)	5.3 (5.0, 5.6)
Other	1.7 (1.6, 1.9)	621	2.0 (1.8, 2.1)	1.4 (1.2, 1.6)
Household	*2.7 (2.6, 2.8)*	*986*	*3.0 (2.9, 3.1)*	*2.3 (2.2, 2.5)*

Source: https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/Program-Evaluation/2014ContractorReports/2014-EMEP-Northeast-Residential-Lighting.pdf

This study reports raw values from the NRL report in lieu of the values adjusted for snapback[20] due to the fact that we are assessing raw values in this study. From responses to survey questions about the use of the installed smart products in this study, we understand that snapback has likely occurred but we have not discounted for it. Therefore, savings could be greater with a snapback factor applied. For

[19] Inefficient bulbs include halogens and incandescent bulbs, and efficient bulbs include CFLs, LEDs, and fluorescent bulbs.
[20] Snapback, or increased use, occurs when a household installs an efficient bulb in a socket and begins using that socket more, because the cost to operate that light is lower.

more information on snapback, and the adjustments made in the NRL report, see the discussion on Page 48 of the NRL report.

Table 10 compares the mean daily hours of use (mean projected annual run-hours, divided by 365 days) for this study with the same factors in comparison to the NRL Study, which had a much larger sample of non-smart bulbs.

Table 10. Comparison of the NRL Study's mean daily hours of use against this study

	NRL Study Bulbs	Smart Bulbs
Kitchen	4.1	3.0
Living space	3.3	2.4
Household	2.7	2.5

Table 11. Comparison of the NRL Study's mean annual hours of use against this study

	NRL Study Bulbs	Smart Bulbs
Kitchen	1497	1095
Living space	1205	876
Household	986	913

Table 11 represents the calculated potential for annual hours of use. In **Table 10 and Table 11**, the percent reduction in hours of use by using smart bulbs could range from 7-27 percent depending on location, with high use locations potentially yielding greater savings potential, with the caveat that our sample size was not statistically significant.

The NRL study bulbs represent non-smart bulbs from a much larger and more reliable sample than those found in our report. In most cases the NRL non-smart bulbs' mean daily HOU (in kitchens, living rooms, and overall household) represent higher usage than the smart bulb mean daily HOU found in this study. Although not statistically significant, from this statement, it would appear that smart bulbs are on for fewer hours a day than non-smart bulbs. This finding, coupled with the study's lower projected annual operating hours for smart bulbs (as compared to our existing non-smart TRM's annual HOU) indicate that smart bulbs may represent an energy saving opportunity. Additional research is needed to confirm this result and further quantify potential energy savings.

PROJECTED ANNUAL OPERATING HOURS: OTHER VARIABLES

While we surveyed and sliced data based on the ancillary variables of percentage of window composition of exterior wall, and number of occupied hours we were unable to draw conclusions from these analyses due to small sample size. You may find these analyses in

Appendix C: Projected Annual Operating Hours: Other Variables, **By Percentage of Window Composition of Exterior Wall** or **By Number of Occupied 9-5 Weekday Hours**. We instead present below the ancillary variables of smart package type and regular use of automation.

By Smart Package Type

Table 12 offers descriptive statistics for each indicated variable. Please note that the sample size of the different product assortment, plus multiple room functionality, makes the below results not statistically rigorous.

Table 12. Projected annual operating hours: by smart package type

	All Bulbs		Smart		Non-Smart	
	Samsung SmartThings	Wink	Samsung SmartThings	Wink	Samsung SmartThings	Wink
Count	62	58	39	33	23	25
Mean	715.96	753.89	921.29	898.86	367.78	562.54
Std	702.43	612.25	771.48	669.60	372.26	474.76
Min	1.48	0.69	28.20	21.25	1.48	0.69
25%	230.36	167.96	495.66	363.32	108.39	132.91
50%	576.46	651.90	721.47	954.03	261.02	378.43
75%	894.46	1,043.31	987.17	1,292.61	460.36	994.49
Max	3,602.04	2,656.83	3,602.04	2,656.83	1,489.40	1,809.19

There is no significant difference between the smart packages among projected annual run-hours for smart bulbs ($p = 0.39$). These data, shown in **Figure 5,** also confirm that no difference exists between smart packages for all bulbs ($p = 0.23$) or for non-smart bulbs ($p = 0.43$). Therefore, the smart package type received is not a confounding factor for results comparing categories within a single bulb type. This suggests that we can draw conclusions about the use of both kinds of smart bulbs, from data collected from homes with both package types.

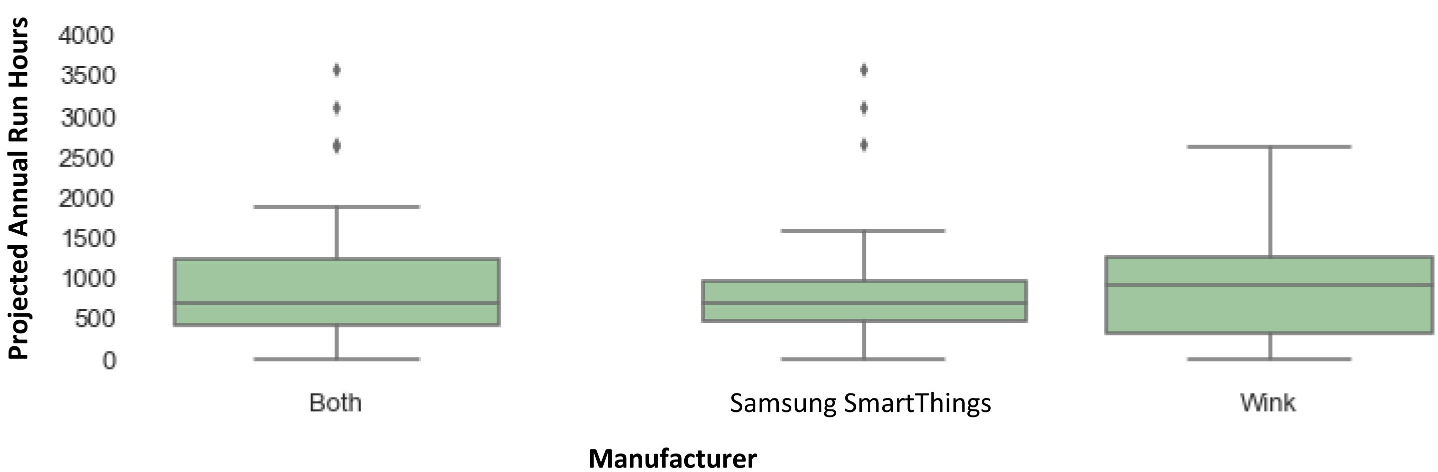

Figure 5. Smart bulbs by smart package type: projected annual operating hours.

By Regular Use of Automation

Smart products allow for different scheduling and automation options. Regular use of automation means that participants reported using automation for the majority of the study to automate processes in their home (i.e. turn bulb on at 5pm). **Table 13** presents descriptive statistics for the indicated variable of regular use of self-reported automation.

Table 13. Projected annual operating hours: by regular use of automation

	All Bulbs		Smart		Non-Smart	
	No (Not Regular)	Yes (Regular)	No (Not Regular)	Yes (Regular)	No (Not Regular)	Yes (Regular)
Count	72	48	42	30	30	18
Mean	704.63	778.79	837.18	1,014.37	519.04	386.17
Std	573.39	771.93	617.96	846.23	451.62	405.78
Min	0.69	28.20	21.25	28.20	0.69	74.34
25%	204.19	206.09	404.41	474.37	116.43	129.48
50%	645.13	551.16	718.55	892.76	391.75	196.14
75%	1,000.33	1,003.31	1,213.11	1,306.32	950.34	477.65
Max	2,656.83	3,602.04	2,656.83	3,602.04	1,809.19	1,489.40

There is no statistically significant difference between projected annual operating hours for smart bulbs in households that used and did not use regular automation ($p = 0.28$). Since these were DIY installations without additional guidance on efficiency scheduling, this finding shows a big opportunity for efficiency in scheduling. It also shows that, given no education or guidance, automation does not necessarily gain efficiency. **Figure 6** offers a visual presentation of these observations.

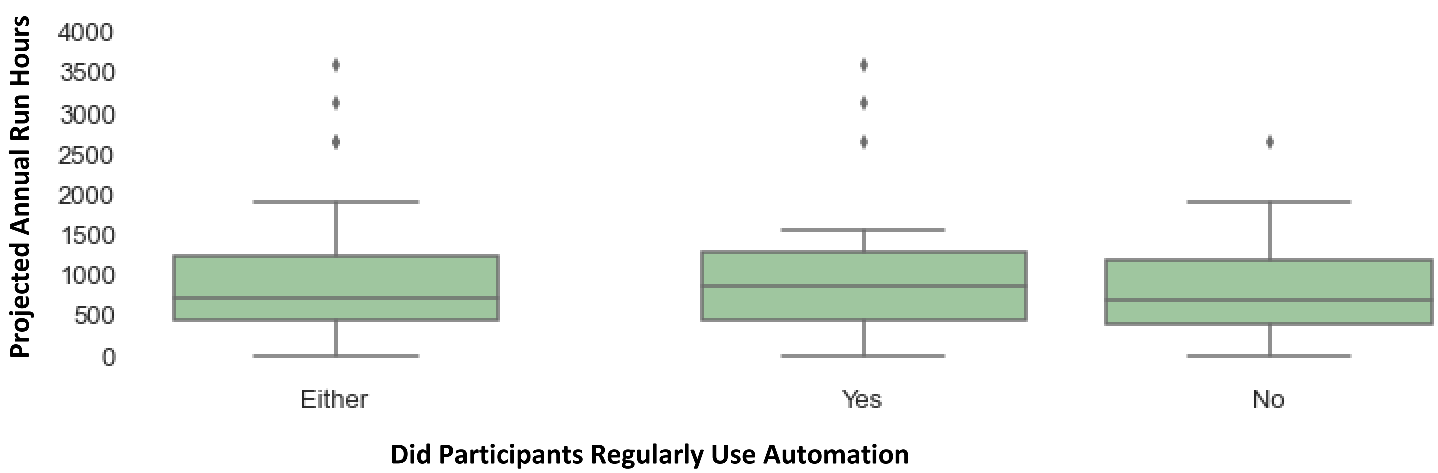

Figure 6. Smart bulbs by regular use of automation: projected annual operating hours.

DIMMING

This analysis used 72 smart bulbs. Because dimming is one of the ways that smart bulbs can save energy, we analyzed the light logger data to determine how often the bulbs were dimmed, and how much they were dimmed. To assess the percentage of bulbs that were dimmed, it was necessary to determine thresholds for how much the light level was reduced, before we considered the light to be dimmed, and how often we observed such dimming before we counted that bulb as one that was "dimmed." We determined these thresholds to avoid falsely categorizing bulbs as dimmed, when the behavior was very infrequent or slight, or if the fluctuations might be due only to minor variations in the logger measurements. **Table 14** shows the count and percentage of smart bulbs that exhibited dimming behavior more than 5, 10, 15, 20, or 25 percent of the time that they are on. Because light level loggers record light intensity and because they can be influenced by environmental factors, the intensity level at which we considered use to be "dimming" varied. That is, a "light intensity threshold" of 10 percent does not necessarily mean that the user has indicated a 90 percent "dim" on their dimmer switch. Consequently, in each table row, we present the number of bulbs for which metering has recorded a light intensity less than the given light intensity threshold, to examine the exact threshold at which to consider reduced intensity to be dimming. Since there is some inherent fluctuation in the measurement, almost all the bulbs report some time below 60 percent. However, at the 40 percent light intensity threshold, we could be more certain that the measured dimming actually reflected a change in operation and not measurement variability. Although we observed 43 percent of bulbs to reach this level at least 5 percent of the time, only 33 percent were dimmed at least 25 percent of the time, based on that threshold. Thus, we conclude that about one-third of our sample exhibits significant dimming behavior.

Table 14. Percent of bulbs exhibiting reduced light intensity by percent of on-time (n = 72)

Light Intensity Threshold	Percent of Bulbs Exhibiting Behavior				
	>5% of on-time	>10% of on-time	>15% of on-time	>20% of on-time	>25% of on-time
0%	0%	0%	0%	0%	0%
10%	18%	17%	12%	10%	8%
20%	26%	25%	21%	19%	18%
30%	31%	29%	28%	26%	26%
40%	43%	38%	33%	33%	33%
50%	75%	72%	65%	61%	53%
60%	99%	99%	99%	93%	82%
70%	99%	99%	99%	99%	99%
80%	99%	99%	99%	99%	99%
90%	99%	99%	99%	99%	99%
100%	100%	100%	100%	100%	100%

To answer the question of what is the average dimming level **Figure 7** shows average light intensity levels recorded across meters, giving the number of meters whose average light intensity level falls within each of ten bins.

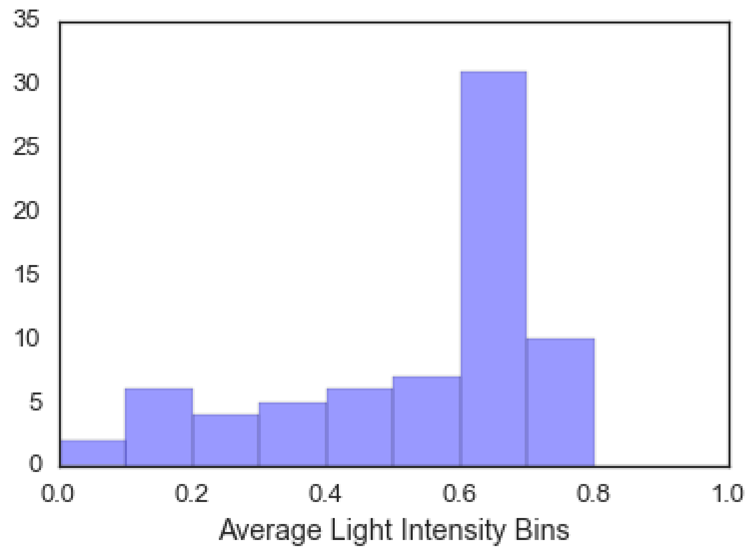

Figure 7. Average Light Level Intensity Binned by Number of Bulbs.

For each bulb in the study, we calculated an average light intensity during the times that it was deemed to be "on." **Figure 7** shows the number of bulbs with different average intensity, so that bulbs that were commonly dimmed are counted in the lower bins (closer to zero), and a bulb that was set only to full-intensity or "off" would be counted in the 1.0 bin, meaning that on average it operated at 100 percent intensity. Due to intrinsic variations in the measurement of light levels, all bulbs registered some time below the maximum intensity, which was used to set the 100 percent level for each bulb, so no bulbs were actually counted in the 1.0 bin.

Most of the bulbs recorded an average intensity of 60-80 percent, which might in fact be consistent with on-off operation (no dimming), and might represent variations only in measurement. To reliably assess dimming behavior, we needed to establish a threshold of light intensity that indicated dimming behavior rather than variation in measurements. By testing different thresholds, we judged 50 percent intensity to be a reasonable threshold of dimming, so that any time that a bulb was on, but below 50 percent of the maximum intensity for that particular bulb, would be considered dimmed time. Based on that threshold, we found that 38 percent of the time the smart bulbs were on, they appeared to have been dimmed.

The exact level of dimming during those hours is difficult to quantify, because of the uncertainty in the dimming threshold. However, it does seem that there was a significant amount of dimming behavior occurring within this trial. Since dimming the bulbs reduces the energy consumption, this aspect of the smart bulbs could result in energy savings beyond any reduced operating hours. This is a big opportunity in the lighting market. In an average home, only about 10 percent of lamps are on dimmer switches. If a homeowner now has control and chooses to dim bulbs 38 percent of the time to varying light levels, there may be quite a bit of efficiency potential. Beyond efficiency gains, smart controllability of dimming levels could also yield future demand response opportunity as a customer may choose to opt into small decreases in light levels in called demand response events. Additional research will be needed to quantify the savings potential, as well as how the types of homes and rooms in which these bulbs are installed might affect those savings.

SMART HUB ACTIVE POWER CONSUMPTION

The smart hubs' power demand ranged from 1.5W to 1.7W of power, with the majority at 1.5W. We metered the hubs to measure their energy use to understand both consumption intensity and consistency of power consumption. Understanding this impact could influence the smart lighting benefits; thus, it needed to be measured. These levels of consumption were very minimal and within expected ranges, as shown in **Figure 8**.

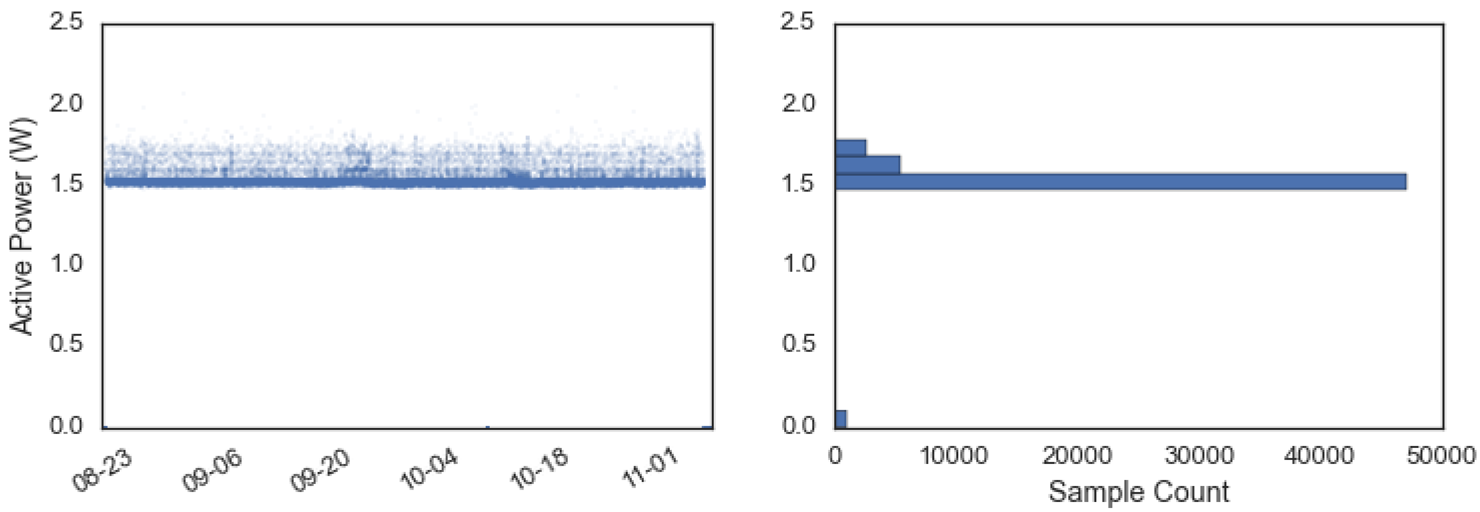

Figure 8. Smart hub active power consumption.

SMART OUTLETS

Initially, many participants reported not plugging anything into the smart outlet at installation because they were not certain about what to plug in. One participant chose to disregard this portion of the study and never plugged anything in, because "it didn't make sense for any of the products we use." At some point throughout the study, at least 67 percent of participants recorded having some sort of lighting device plugged in (lamps, lighted ornaments / string lights, or night lights). Additionally, a few participants recorded seasonal installations; 26 percent of participants noted plugging in air conditioners or dehumidifiers. Among the less frequently plugged-in items, 2 participants recorded plugging in a TV, and 3 participants recorded using a hot beverage machine or accessory. In a home that is very heavily outfitted with smart bulbs, a smart outlet might not make sense in most use cases. This could explain why participants struggled with what to plug in, and was evidenced by a participant who initially plugged in a lamp containing a smart bulb, only to realize later that this was not a good use for the outlet. That is, the participant already had the same control plus dimming that was needed through the smart bulb.

Table 15: Smart outlet – survey responses for plugged in products

Participant	Product Plugged In				
	Response at the Start of the Study (Survey 1)	Response at the Conclusion of the Study (Survey 2)			
	At Installation	First Product	Second	Third	Fourth
A	Nothing.	None; it didn't make sense for any of the products we use.			
B	Nothing, so far… Might use it for irons (clothes iron, hair straightening iron, waffle iron)	Lamp with broken switch	Dehumidifier		
C	Didn't yet cannot connect to wink hub.	TV	Bedroom light		
D	Air conditioner	Air conditioner - only disconnected after summer/no need for AC	Fan - never worked because didn't have 3 prongs		
E	Living room lamp	Main lamp in living room			
F	Air conditioner	Air conditioner - weather changed	Bedside lamp		
G	Keurig	Lighted ornament	Coffee pot		
H	Air conditioner	Air conditioner			
I	Nothing yet.	A string of LED lights.			
J	String of Lights.	Lamp	Lamp	Lamp	Mini lights
K	TV	Kids light in room	TV/DVR		
L	A lamp	Lamp - Unplugged it because lamp in other room would get more use.	Lamp		
M	Nothing yet.	Electric Water Heater for tea			
N	Living room lamp	Lamp - I didn't need it plugged in the smart outlet since it was a smart bulb	iPhone charger – unplugged as I don't usually keep my charger in one place, I bring it with me	Night light	
O	Coffee grinder	Coffee grinder			

IMPROVING THE USER EXPERIENCE

When asked what, if anything, could be done to improve user experience using smart home products, participant responses generally fell into one of four categories. Participants either made suggestions for improvements to the app / product, noted installation challenges, indicated potential bugs affecting energy efficiency, or suggested that advanced features / product upgrades would have improved their overall experience.

Application / Product Suggestions

Two participants indicated that the application (app) was complicated and not very intuitive. They both struggled with turning the lights on and off, or navigating the app, and never changed the settings assigned at installation. When installing the products, one participant automated some bulbs to turn on / off when they left, using the HEMS app. However, the other house occupant was negatively affected when the primary user left and the lights turned off. The participant was unable to change this feature throughout the course of the study, or to correct for it with an IFTTT statement that would turn off the bulbs only if both smart phone users left the house.

One participant indicated that he would love to use the GPS locator to turn bulbs on when he arrived home, but that it drained the battery. This problem is not something that the manufacturers can necessarily address with the application, but it might be addressed by advanced features / product upgrades as indicated in a later section.

Finally, participants noted smaller app improvements or product labeling changes. One participant stated that the smart outlet should indicate somewhere that it does not work with all appliances. He tried to hook it up to his dehumidifier and it wouldn't work. Another participant suggested that there should be iPad support for the app. Two others noted improvements that could be made to the product icons—for example, taking real fixture photos to more quickly choose the appropriate lamp, or to connect two fixtures to one icon (which might be an advanced feature that the customer didn't enable).

Installation Challenges

When asked about what could be done to improve their experience, a few participants noted installation challenges: getting the hub up and running, and difficulty in setting up the outlet. The latter case could be resolved only with several e-mails to the manufacturer. A third participant found that the smart bulbs lost their connection quite a few times and needed to be reset. Beyond that, some of their bulbs needed to be removed and reprogrammed with the hub. The participant couldn't tell if this was due to the wireless internet connection or to the product itself, but found the app and product help page in particular to be very user friendly.

Potential Energy Implications

Three participants expressed concern about bulbs turning on unexpectedly, or forgetting to turn bulbs off via the app. Another participant noted that if the bulb was reset via the wall switch, the dimmer setting would also reset to 100 percent or full brightness. All of these situations carry energy and measure life implications that should be considered in future discussions with manufacturers.

- The idea behind [the smart home system] is great. The smart outlet is probably the item we found most useful. Unfortunately, some of the light bulbs would flicker from time to time, and on a few occasions, after turning them off with the app, they would turn back on. It was sort of funny, but not exactly energy efficient if you leave the room and don't realize the light turned back on of its own accord. Towards the end of the study we actually used the app less than in the beginning because we would get a bit frustrated that the bulbs wouldn't follow the commands properly.

- I noticed that I would often leave more lights on (all of the smart bulbs), thinking I would leave and turn them off in the car... only to return hours later having left all of the lights on. I also found that they were not useful in the bathroom except when I used the **bath relax setting**. Since we use the bathroom lights so often it was easier to use the wall switch. Overall, I am light sensitive person. I like the lighting to be just right. At one finger, I have access to get the lights right with one setting. I really like the system.

- When the power blinked off, all connected lights turned on afterwards. I was lucky enough to be home at the time, so able to turn everything off, but I'd be really unhappy to have this happen while I was away.

- Most importantly, when the lights are set with a dimmer setting, if the switch is used to turn the lights off or on, the dimmer setting resets to 100%. This is annoying and pointless. The lights should be able to go back to their dimmer setting once turned on and off with the app.

Advanced Features / Product Upgrades

Four participants identified areas of improvement that could be addressed by using advanced features, product upgrades, or additional smart products. Two of those participants noted challenges with adding another person / smart phone to the system. This is an advanced feature, similar to scheduling, that Efficiency Vermont did not assist with, over the course of the study. One participant was unable to invite her husband as a user, so they installed it with her account on his phone, and both could not be logged in at the same time. This problem could have been resolved by reaching out to customer support, but this issue, in addition to another participant's issue, indicate that adding multiple smart phones might not be as easy or as user-intuitive as it could be.

Three of the four participants noted challenges with the smart home setup, visitors, and a traditional wall switch. The participant issues noted below could have been resolved with the additional purchase of select models of smart wall switches:

- …Is not good for any households who has visitors ever. If I flip the light switch with a smart bulb on, and then turn the light off with my phone, it is stuck off unless you use the phone to turn the lights back on. The switch becomes useless, which was annoying when we had our neighbor check in on our dog at times during the study.

- We found that when having someone in the house without access they had to toggle on and off the switches and that we could not control them until we came and reset them.

- The other issue we had was that you had to have the light switch in the on position to use the app, so we couldn't turn on the light remotely if we hadn't turned it off with the remote.

In suggesting additional products that could improve user experience or alleviate problems, we are brought back to our original question about the consumer's threshold for associated product costs. Efficiency Vermont decided at the beginning of this study to identify the lowest possible entry point for consumers with product selection. Naturally, some participants will both require and prefer advanced levels of functionality. Future studies regarding the consumer threshold for associated product cost, as well as the impact of advanced functionality on product savings will be helpful as we consider our engagement with this space.

BEHAVIORAL CHANGES

Efficiency Vermont asked participants how the smart products changed their interactions with their home, or alternately if they found themselves reverting to non-smart methods / devices as the study progressed. Only 13 percent of participants noted abandoning advanced features or smart functionality.

- I sort of became lazy and wouldn't turn on as many lights because I would have to get out my phone to turn them on, so sometimes when I had my hands full I would just walk around in the dark because it was easier than finding my phone and opening the app and turning the lights on. But it was helpful because we could turn off the lights from afar when we had left the house.
- I tried programming our kitchen lights for my wake up time, but stopped after a handful of times because I was worried I hadn't programmed the lights to go back off after I left so just flipped the wall switch to be sure. We have always turned off lights we're not using.

Many participants noted that the products have affected their interactions with their homes in ways that increase their homes' comfort. Most participants discussed the ways that it affected their return home, or morning / evening routines. A few participants discussed the seasonality of these changes, and a few others mentioned already expanding their smart home suite. These interactions could be perceived to increase or decrease energy use, because they modify behavior. Efficiency Vermont's study found that energy use was not significantly increased with the use of smart products. However, the small sample size precluded the reliability of these results. Further study is needed with an increased sample group, and preferably with pre- and post-installation energy use data to fully understand the energy effects stemming from any behavior modification. Some participant responses illustrate the way that smart lighting could affect the end user's experience with home lighting.

- I programmed lights to switch on/off at certain times of the day when I knew it would be dark out and I would be home. It found the smart bulbs to be more useful as the study went on especially after daylight savings when I would arrive home from work after dark.

- I was able to leave lights off even though I'd be home after dark, as I could turn them on as I got closer to home - this was great!

- Not waiting till I get home to turn the air conditioner on. With the outlet I can power as soon as I leave for home to get cooled off.

- I have lights programmed to come on in the morning before sunrise (which makes sense in winter), and I have them come on just before I get home (also likely only in winter). They are also programmed to turn off at a certain time, in case we forget. We also have the Cree lights set to a dimmer setting of 50-75%, and use the other lights less.

- I purposely turn the lights off with my phone before I go to bed, so that I will be able to see the whole time during my walk to bed. I also keep better track of my phone and try to remember to keep the light switches on so that I can turn lamps on from my car when I get home at night. I like to mess with my husband and turn the lights off on him if he is home first.

- I found I would actually have more lights on and leave the lights on more than I think I would if I were turning them all on separately. I found the Bathroom not helpful. I love the Good Morning routine. Lights were like an alarm... I also like going to bed and turning the lights off when we were all upstairs.

- The dimming feature in the living room was great when watching TV or nursing my baby (especially being able to adjust it from my phone without getting up).

- Better about turning off lights.

- I bought an extra bulb for outside and programmed it to run on a schedule.

Conclusion

This study investigates the potential of the smart-home and the connected electronics industry with an eye toward the opportunity and barriers to energy efficiency. It offers insights and suggestions into how the future of the industry can be moved to better coordinate with the objectives of energy efficiency programs. These objectives might range from short-term needs, such as customer engagement and energy savings, to longer-term interests, such as greater efficiency integration, demand response, data-sharing, and integration with distributed energy resources.

This pilot successfully achieved its objectives outlined in the **Study Approach.** We tested a new kind of light bulb that is controlled by a Home Energy Management System hub, and conclude that the technology holds promise as a new initiative for energy efficiency programs. The analysis of the data obtained under this project have served two purposes: (1) it evaluated ways in which the products are being used in real-world conditions, and (2) it explored how the data communicated by these devices can inform consumers' energy efficiency decisions. The study enabled analysis of effectiveness under several, real-world conditions, but does not offer insights on the technology's true savings potential for smart light bulbs due to the inability to draw statistically significant conclusions from the constrained study's sample size. However, initial trends emerging from this study indicate a few insights.

SMART BULB SAVINGS POTENTIAL

Smart light bulbs appear to yield lower hours of use that may equate to lower energy usage when compared to Efficiency Vermont's established baselines[21] for non-smart lighting. Although not statistically significant, the pilot shows especially promising results for comparing HOU for smart bulbs in all usage areas to non-smart bulbs from the NRL report; and greater opportunity in smart bulbs in high use areas versus baseline non-smart bulb hours of use in those same areas of the home. In this small sample, we saw an up to 27% reduction in usage with smart bulb use. While these are potentially preliminary indicators, more research is required to statistically guarantee these savings.

DIMMING

In addition, dimming seems to be a very real opportunity. The pilot also showed by adding the opportunity of dimming where none existed, people dimmed their bulbs, equating to potential energy savings. Dimming has the potential to yield some significant energy savings. From this effort, a significant amount of dimming behavior occurred within this trial. Since dimming the bulbs reduces the energy consumption, this aspect of the smart bulbs could result in energy savings beyond any reduced operating hours. This is a big opportunity in the lighting market. In an average home, only about ten

[21] Efficiency Vermont uses the NRL study referenced above for baseline assumptions which draw from a statistically significant sample size.

percent of lamps are on dimmer switches. If a homeowner now has control and chooses to dim bulbs 38 percent of the time to varying light levels, there may be quite a bit of efficiency potential as well as demand response opportunity. Additional research will be needed to quantify the savings potential, as well as how the types of homes and rooms in which these bulbs are installed might affect those savings.

AUTOMATION

In addition, there was no statistically significant difference between projected annual operating hours for smart bulbs in households that used and did not use regular automation ($p = 0.28$). Since these were DIY installations without additional guidance on efficiency scheduling, this finding shows a big opportunity for efficiency in scheduling. Our hope is that this study provides direction and offers insights into how to collaborate and influence the future state of the smart industry. These objectives might range from short-term needs, such as customer engagement and energy savings, to longer-term interests, such as demand response, data-sharing, and integration with distributed energy resources.

SMART OUTLETS

In addition, the study catalogued consumer usage of smart outlets. We also met the corollary objective of obtaining information on user experience of HEMS devices. At one point in the study, at least 67 percent of participants recorded having some sort of lighting device plugged in (lamps, lighted ornaments / string lights, or night lights). However, due to the additional dimming capability of the smart bulb, the outlet control function did not add value over a smart bulb if one was available in most cases.

USER EXPERIENCE

Users are enthusiastic about the energy and cost savings they can achieve with this combination of technologies. The strong response to our request for participants indicates that smart homes represent a major opportunity for efficiency programs to engage with a highly motivated market. All respondents who began the study participated fully throughout the study period.

This study represents an ideal smart home setup, with major smart home industry barriers removed through product selection. Within that context we found that participants were largely able to install the smart products on their own, in an environment that mirrors a retail purchase experience. Participant survey responses offer a very full understanding of the challenges with the equipment, particularly in set-up. Despite these challenges, 47 percent of participants were surprised by how easy it was to install the product. Others were able to resolve their installation challenges upon engaging with the manufacturer's support tools. Efficiency Vermont believes that there is opportunity for a retail program initiative based on these results. Further study is needed to evaluate post-installation measure life. Will consumers keep these products connected to the grid, or do they represent a novelty?

Participants were primarily interested in the ability to remotely control smart bulbs, and many were interested in dimming capabilities. They enjoyed the ability to dim fixtures which were not previously dimmable, or control only one bulb in a circuit. For that reason, many struggled with finding a good use for the smart outlet after converting the bulbs to smart bulbs. As one participant noted, smart bulbs provided them with the same control as a smart outlet, but with the additional benefit of dimming. Future studies focused on smart lighting should study smart outlets and smart bulbs separately.

Overall, participants' satisfaction with smart products is high: 80 percent said they were "satisfied" or "very satisfied" with the HEMS hub; 87 percent said they were "satisfied" or "very satisfied" with smart bulbs; and 74 percent signaled similar satisfaction with the smart outlet.

INDUSTRY SIGNIFICANCE

This study is the first of its kind to assess smart lighting and HEMS in real-world settings, with a nearly universal efficient product, light bulbs. Although the study sample is small, we were able to answer many of the questions that we set out with.

There are a number of ways that energy efficiency programs can engage with this market. Understanding challenges with installation and use allows efficiency programs to partner with manufacturers in optimizing performance and functionality, thereby ensuring persistence of savings, as well as opportunities to engage with customers directly. We noted no significant difference in the projected annual operating hours of those who regularly used automation against those who did not. Further, 13 percent of participants reported that they would find use cases helpful, but they might not have understood the benefits of having the use cases. Additional research is warranted to determine if there are efficiency gains in efficiency program education and assistance regarding use cases or schedule / automation optimization.

This study centered around two different manufacturer's certified-compatible HEMS ecosystems, and found no significant difference in projected annual hours of use between the two ecosystems. This suggests that efficiency programs could be scalable across products provided that there were strict selection criteria for qualified products.

Customers value these products - nearly all participants reported their experience with the products to be neutral, satisfied or very satisfied at the conclusion of the study. Furthermore, knowing the cost of the products 73 percent of participants would recommend at least the smart bulb and hub to a friend. Forty-seven percent of participants would recommend the entire smart home suite, including the smart outlet, to a friend. As the lowest-cost entry point to the smart lighting market, we have not surpassed customer's pain threshold for associated costs. Additional study (see **Appendix D: Recommendations for Future Study**) is warranted to determine when the customer's pain threshold for additional costs, features, and subscriptions is met, as well as the additional energy savings that may be achieved through advanced functionality.

Overall, there is promise in this space and we look forward to these findings helping to build a greater understanding and energy savings from smart lighting and home energy management systems.

Appendix A: Distribution of Operating Hours by Room Type & Investigation of Kitchen and Living Room

DISTRIBUTION OF OPERATING HOURS BY ROOM TYPE

Figure 9, Figure 10, and **Figure 11** show the distribution of the mean and variability among projected annual operating hours between the different rooms for all bulbs, smart bulbs, and non-smart bulbs, in turn.

Interpretation for the box plots:

- Box shows the interquartile range.
- Whiskers extend 1.5x past the low and high quartiles
- Points outside this range are outliers and shown as diamonds

Understandably, the kitchen and living room show the largest projected annual operating hours of the various room types. The sample size for all other rooms is in most cases too small to offer anything other than anecdotal information. Descriptive statistics for a subset of all other rooms (bathroom, dining room, bedroom) can be found in **Appendix B: Descriptive Statistics for Low-Sample Room Types Table 20**.

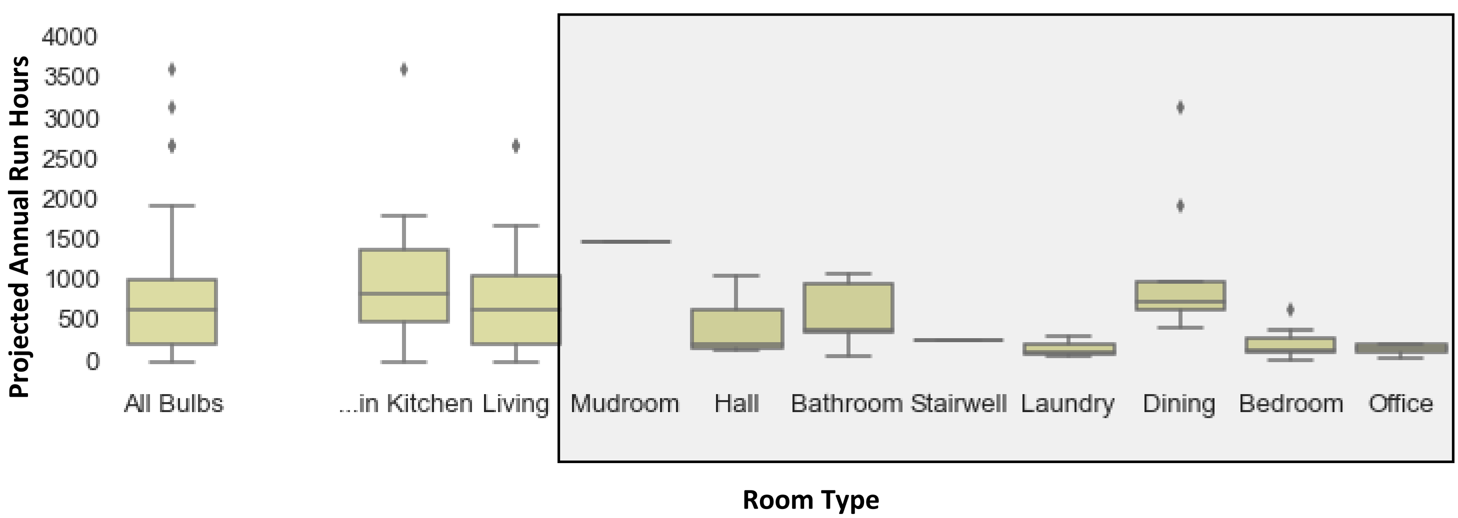

Figure 9. All bulbs: projected annual operating hours by room type.

Looking only at smart bulbs, we see that the dining room represents the highest use of the study, although that room is associated with only 5 bulbs, whereas the kitchen represents 24 bulbs, and the living room represents 34 bulbs. Two of the 5 smart bulbs in the dining room relate to an open concept kitchen / dining room, which might also explain why use is higher in this room.

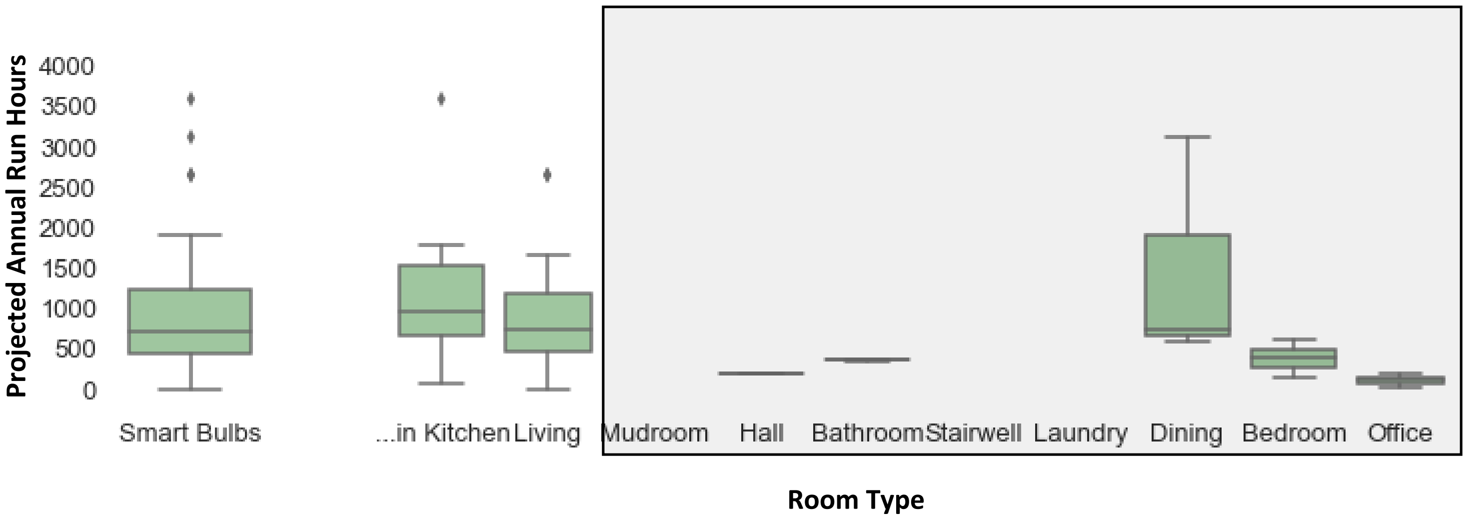

Figure 10. Smart bulbs: projected annual operating hours by room type.

Figure 11 shows the distribution of non-smart bulbs across varying room types. The small number of metered non-smart bulbs in our highest HOU rooms is most likely attributable to the fact that most available sockets were occupied by a smart bulb. Looking at our most reliable HOU comparison categories (kitchen and living room), it is important to remember that there were only 8 bulbs in the kitchen and 6 bulbs in the living room. The non-smart bulbs generally appear to have less differentiation in projected annual run-hours than the smart bulbs, but the non-smart bulbs may not reflect dimming capabilities; it does not indicate the effects of any kind of scheduling or advanced control.

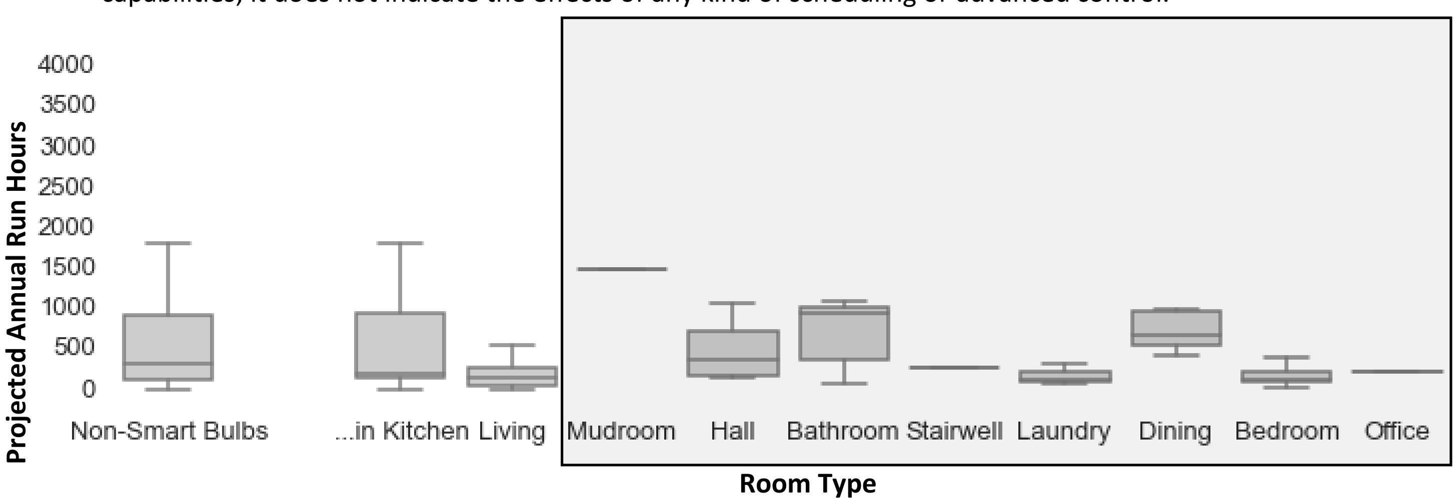

Figure 11. Non-smart bulbs: projected annual operating hours, by room type.

Figure 12 compares smart and non-smart bulbs in the most-metered rooms, the living room and kitchen.

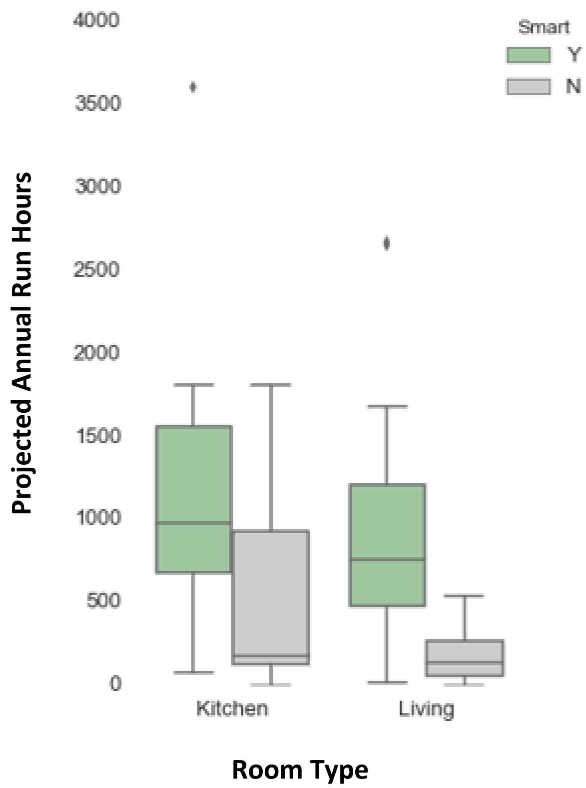

Figure 12. Smart vs. non-smart bulbs: projected annual operating hours in well-metered room types.

Across these room types, the mean projected annual operating hours of use differ, and their range appears quite large between smart and non-smart bulbs. However, as we know from **Table 7. Number of light level loggers per room type**, the number of metered non-smart bulbs in kitchen and living rooms is also small, which makes any conclusions unreliable with regard to non-smart bulb use from these rooms.

Given those effect sizes, and under some assumptions we list below, a power analysis determined the number of samples necessary to reach a 90 percent level of statistical power for a few comparisons between our most metered rooms. We also estimated our actual statistical power, given the effects we observed given our sample sizes.

Table 16. Significance test: Estimated statistical power of selected room comparisons

Comparison	Observed Effect	Number of Samples in Group 1	Number of Samples in Group 2	Desired Statistical Power	Minimum Necessary Samples in Group 1	Minimum Necessary Samples in Group 2	Estimated Statistical Power
Kitchen smart vs. non-smart bulbs	0.86	24	8	0.90	24	24	0.76
Living room smart vs. non-smart bulbs	1.03	34	6	0.90	17	17	0.94

Table 16 shows that the statistical power for smart vs. non-smart bulbs in kitchens is lower than 90 percent, and the number of samples necessary is larger than the number in the dataset. Consequently, the reliability of our results for that comparison is lower than ideal, given the limitations in test power. The numbers in **Table 16** are actually best-case scenarios; we made simplifying assumptions in the calculation of statistical power that groups have equal numbers of samples, and that each group has the same standard deviation. We used the mean of the two sample sizes for the former, and the standard deviation for all bulbs together for the latter. We also assumed a desired significance level of 0.10 during any comparisons. That is, we strove for a minimum of 90 percent confidence that a difference in projected annual operating hours actually exists between two rooms.[22]

INVESTIGATION OF KITCHEN AND LIVING ROOM

Comparing bulb use in kitchens and in living rooms needs to be complemented by a comparison of bulb use in kitchens *or* in living rooms, relative to all other bulb use. The study used this approach to discern the significance in differences between rooms and bulb types. **Table 17** and **Table 18** draws the distinctions between smart vs. non-smart bulbs.

The following descriptive statistics refer to the projected annual operating hours.

[22] Note that this is also the level of significance adopted in the Northeast Residential Lighting study (see **Comparison of Operating Hours to Northeast Residential Lighting (NRL) Study)**.

Table 17. Projected annual operating hours: kitchen and living rooms

	All Bulbs		Smart		Non-Smart	
	Kitchen	Living Room	Kitchen	Living Room	Kitchen	Living Room
Count	32	40	24	34	8	6
Mean	960.08	766.25	1,101.01	867.81	537.28	190.72
Std	735.84	651.08	724.41	651.21	633.47	199.94
Min	1.48	0.69	80.88	21.25	1.48	0.69
25%	497.85	207.30	682.92	480.70	131.86	52.22
50%	838.69	639.98	980.34	756.52	178.81	134.18
75%	1,391.53	1,061.68	1,564.80	1,213.11	924.89	270.72
Max	3,602.04	2,672.12	3,602.04	2,672.12	1,809.19	534.15

The mean values appear different between the two areas across bulb type with the kitchen, in all cases, averaging higher use than those in the living rooms. In terms of annual operating hours, smart bulbs appear to be used more frequently than non-smart bulbs. This could be due to our asking participants to install smart bulbs in the kitchen and living room only, and thus any non-smart bulbs installed in these rooms could be in a lesser-used fixture. Additionally, in comparison to the mean, the standard deviation is very high, representing a wide amount of data spread. This indicates that the variation among projected annual run-hours in a single room is large. For that reason, we have also included information regarding significance testing listed below.

Table 18 offers aggregate statistics for bulbs in kitchen and living rooms, combined, as well as bulbs outside those room types. These data can inform significance tests to confirm these relationships.

Table 18. Projected annual operating hours: kitchen and living rooms combined

	All Bulbs		Smart		Non-Smart	
	Kitchen or Living Room	Not Kitchen or Living Room	Kitchen or Living Room	Not Kitchen or Living Room	Kitchen or Living Room	Not Kitchen or Living Room
Count	73	50	58	14	15	36
Mean	844.05	546.89	964.31	690.21	379.03	491.15
Std	690.73	557.85	686.07	845.67	495.73	398.28
Min	0.69	8.60	21.25	35.16	0.69	8.60
25%	297.04	151.48	525.59	205.16	102.65	127.29
50%	725.76	384.36	830.18	391.04	191.76	372.37
75%	1,110.15	773.20	1,324.46	681.26	415.60	908.13
Max	3,602.04	3142.15	3602.04	3142.15	1809.19	1,489.40

Significance testing with Welch's t-test confirms the difference between the rooms, comparing the mean projected annual operating hours. **Table 19** provides the observed differences and trend in mean values.

Table 19. Welch's t-test: Are select room comparisons significantly different?

Comparison Type	Significant Difference	Not a Significant Difference
All bulbs in kitchen vs. all bulbs in living room		p = 0.24
Smart bulbs in kitchen vs. non-smart bulbs in kitchen	**p = 0.08**	
Smart bulbs in living room vs. non-smart bulbs in living room	**p = 0.06**	
Smart bulbs in kitchen vs. smart bulbs not in kitchen or living room	**p = 0.03**	
Smart bulbs in living room vs. smart bulbs not in kitchen or living room		p = 0.38
Smart bulbs in kitchen vs. smart bulbs in living room	**p = 0.07**	
Smart bulbs in kitchen vs. all bulbs in kitchen or living room	**p = 0.01**	
Smart bulbs in living room vs. all bulbs in kitchen or living room		p = 0.66
Smart bulbs in kitchen or living room vs. non-smart bulbs in kitchen or living room	**p =0.01**	
All bulbs in kitchen or living room vs. all bulbs not in kitchen or living room		p = 0.13
Smart bulbs in kitchen or living room vs. smart bulbs not in kitchen or living room		p = 0.13

From this, we can say that smart bulb use in kitchens appears distinct from both uses in living rooms and in the rest of the house. We can also infer that smart bulbs have higher use in the kitchen than in any other room of the house, given both tables' listing of mean projected annual operating hours. Smart bulbs in living rooms, on the other hand, are not distinct from the rest of the house, and they do not appear to be used more or less than the rest of the house (excluding the kitchen). Overall, smart bulbs in both kitchens and living rooms appear to be used more than non-smart bulbs in the same room. Again, this is likely due to the fact that smart bulbs in the living room / kitchen were placed in the highest-use fixtures, whereas any other non-smart bulbs in those rooms were placed in lesser-used fixtures.

Appendix B: Descriptive Statistics for Low-Sample Room Types

Table 20 offers descriptive statistics for the next three most-metered areas among our sample households. These statistics indicate that, with the exception of bulbs in bathrooms, smart bulbs appear to be used more frequently than non-smart bulbs. However, because of the low sample sizes, we have insufficient confidence in the validity of these conclusions.

Table 20. Projected annual operating hours: bathroom, dining rooms, and bedrooms

	All Bulbs			Smart Bulbs			Non-Smart Bulbs		
	Bathroom	Dining	Bedroom	Bathroom	Dining	Bedroom	Bathroom	Dining	Bedroom
Count	12	12	8	3	5	2	9	7	6
Mean	580.34	1010.92	221.42	381.80	1,425.31	402.26	646.51	714.93	161.14
Std	382.35	779.77	204.77	16.02	1,098.34	341.46	425.72	255.33	133.96
Min	59.10	405.08	8.60	363.32	618.84	160.81	59.10	405.08	8.60
25%	360.75	639.62	106.70	376.81	693.77	281.53	353.03	525.81	98.22
50%	391.04	724.07	137.34	390.29	754.37	402.26	927.77	657.25	112.41
75%	967.66	994.49	290.37	391.04	1,917.44	522.98	997.06	948.04	224.23
Max	1,071.05	3,142.15	643.70	391.79	3,142.15	643.70	1,071.05	994.49	378.43

Appendix C: Projected Annual Operating Hours: Other Variables

BY PERCENTAGE OF WINDOW COMPOSITION OF EXTERIOR WALL

Table 21 offers descriptive statistics for each indicated variable. We use bulbs only in the kitchen or living room, since the survey question asked about window coverage in these two rooms.

Table 21. Projected annual operating hours: percentage of window composition of exterior wall

	All Bulbs			Smart Bulbs			Non-Smart Bulbs		
	0-25%	26-50%	51-75%	0-25%	26-50%	51-75%	0-25%	26-50%	51-75%
Count	25	35	13	19	27	12	6	8	1
Mean	1,131.71	591.31	971.28	1,282.18	706.31	1,041.49	655.21	203.19	128.71
Std	834.50	456.53	709.33	846.38	433.12	692.08	636.61	303.89	-
Min	28.20	0.69	80.88	28.20	21.25	80.88	191.76	0.69	128.71
25%	534.15	180.04	506.28	892.76	481.48	609.18	211.11	33.44	128.71
50%	996.48	619.98	950.55	1,036.67	662.95	952.29	388.54	104.75	128.71
75%	1,576.50	774.53	1,396.21	1,689.43	905.53	1,420.35	848.09	192.09	128.71
Max	3,602.04	1,609.94	2,656.83	3,602.04	1,609.94	2,656.83	1,809.19	915.61	128.71

Among smart bulbs, houses with exterior walls composed of 26-50% windows in their kitchen and living rooms have shorter mean projected annual operating hours than those with either 0-25% or 51-75%. However, the difference is only statistically significant between 26-50% and 0-25% ($p = 0.06$) and not between 26-50% and 51-75% ($p = 0.17$). There is also no significant difference between 0-25% and 51-75% ($p = 0.65$). As might be expected, the operating hours for homes with 26-50% windows is shorter than those with 0-25% windows, but (curiously) it is also shorter than for those with 51-75% windows. There may be other factors of the home that are correlated with the decreased operating hours for homes with larger percentage of windows. However, because there were only three homes in that category, no meaningful trend can be derived. **Figure 13** offers a visual presentation of these observations.

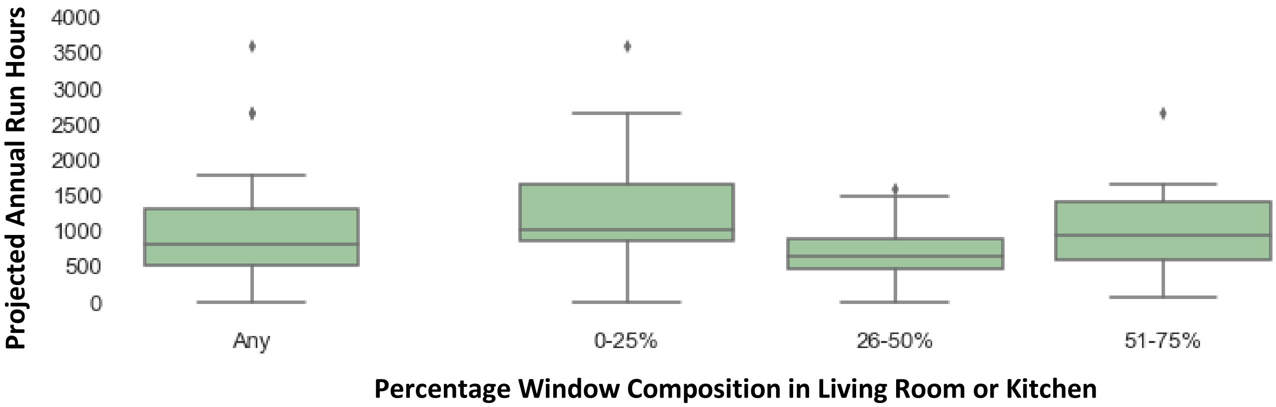

Figure 13. Smart bulbs in kitchen or living room by percent of window composition of exterior walls in kitchen or living room.

BY NUMBER OF OCCUPIED 9-5 WEEKDAY HOURS

Table 22 offers descriptive statistics for each indicated variable when examining for occupied 9-5 weekday hours.

Table 22. Projected annual operating hours: number of occupied 9-5 hours

	All Bulbs			Smart Bulbs			Non-Smart Bulbs		
	0 hours	1-4 hours	5-8 hours	0 hours	1-4 hours	5-8 hours	0 hours	1-4 hours	5-8 hours
Count	44	49	27	29	29	14	15	20	13
Mean	932.40	457.92	913.02	1,121.16	552.70	1,217.93	567.47	320.50	584.65
Std	531.84	382.36	999.91	449.69	356.18	1,284.11	497.83	385.73	393.24
Min	74.34	0.69	8.60	208.38	21.61	21.25	74.34	0.69	8.60
25%	447.23	139.14	275.59	929.80	204.23	370.06	174.44	76.60	187.86
50%	977.17	405.08	618.84	1,045.52	635.31	550.94	353.03	174.44	646.55
75%	1,350.36	721.47	1,003.30	1,492.79	735.73	2,471.98	942.81	405.08	994.49
Max	1,809.19	1,609.94	3,602.04	1,807.16	1,609.94	3,602.04	1,809.19	1,489.40	1,071.05

Significance testing on smart bulbs shows that the projected annual run-hours for 0 hours of occupancy is significantly different from 1-4 hours occupancy (p = 0.00), but not from 5-8 hours occupancy (p = 0.17). Further, 1-4 hours occupancy is not different from 5-8 hours occupancy (p = 0.46). Thus, despite the observed difference between the smart bulb run-hour means for 1-4 hours occupancy and 5-8 hours occupancy, the variability for 5-8 hours occupancy is so large that we cannot be confident that there is a real difference. This variability could be affected by the fact that the 5-8 hours participants accounted for only three households and had the largest number of smart bulbs installed outside the living room or kitchen. For that reason, one might conclude that the difference in run-hour for smart bulbs can be compared only in terms of occupied hours—that is, occupied vs. not occupied.

Appendix D: Recommendations for Future Study

While we are unable to draw statistically significant conclusions from our results, this study identified a number of areas where future studies could build upon our findings. Further study by others would significantly contribute to available smart home literature, and could create a body of data from which a technical reference document could be developed.

- This study attracted participants who are comfortable with technology products. To increase the industry's understanding of how scalable effective HEMS products can be, more study is needed among participants who are not comfortable with technology. This will ensure that efficiency programs offering retail-level efficiency measures can claim a more accurate measure life and persistence of savings.
- Further, the participants in this study largely expressed an interest in how these products might save energy, or in energy efficiency generally. Our initial findings indicate that there is a possibility for energy savings within this motivated group. Additional study is needed with a larger sample that more accurately represents the general population's interests.
- Future studies building upon our model should strive for a better balance of smart and non-smart bulbs in the highest Hours of Use areas of the home. A larger sample size should help to better balance this as it will draw from a larger body of data.
- Our study was only able to scratch the surface of many questions impacting this market. While we determined that DIY installation was not a major barrier to initial measure life, further study is warranted to determine if these products remain connected to the grid over a longer period of time. Will these products still be used as intended, or will users revert to the low-tech light switch? Do they represent a novelty that will wear off, or an opportunity to optimize performance and energy savings?
- There was no statistically significant difference in projected annual Hours of Use from homes that regularly used automation to those who did not. Further study is needed to determine if education on efficient scheduling and automation will impact energy use.
- At the lowest-cost entry point to the smart lighting market, we did not exceed consumer's cost threshold for associated costs. Additional research with optional added features such as smart wall switches, occupancy sensors, geolocator beacons, or subscription services is needed to determine how much customers are willing to pay to make their home smart. Further, what additional energy savings can be captured by these advanced features?
- This study exhibited a significant amount of dimming behavior – 38 percent of the time smart bulbs were on, they appeared to be dimmed. Dimming represents an opportunity for increased energy savings beyond reduced Hours of Use, which was the focus of this study. Additional research is needed to determine the impact of dimming behavior. An ideal study would involve

smart manufacturers sharing the dimming level that the user had set the bulb at with researchers.