Home Energy Management Systems (HEMS): Demonstrations In New York City and Westchester Residences

Final Report | Report Number 19-13 | March 2019

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Home Energy Management Systems (HEMS): Demonstrations In New York City and Westchester Residences

Final Report

Prepared for

New York State Energy Research and Development Authority

Albany, NY

Ryan Moore
Project Manager

Prepared by

National Renewable Energy Laboratory

Washington, D.C.

Lieko Earle
Bethany Sparn
Project Managers

NYSERDA Report 19-13 NYSERDA Contract 81716 March 2019

Notice

Abstract

This report describes the findings of a recent home energy management systems (HEMS) demonstration project conducted by NREL, in collaboration with Con Edison, from 2017 to 2018. Funded by NYSERDA, the demonstration project aimed to conduct an end-to-end demonstration of practical HEMS packages that can be deployed at scale, using commercially available technologies. The main objectives of this effort were to implement simple HEMS solutions for lighting, space conditioning, and plug loads in single-family homes (SFHs) and multifamily units (MFUs) in Con Edison's service territory—and to develop technology transfer strategies based on the insights gained during the implementation process. A particular focus was placed on stakeholder education to help promote the benefits, including the energy savings potential, of HEMS technologies across New York State and to achieve wide-scale adoption of proven products and strategies.

Keywords

Home energy management systems (HEMS); home area networks (HANs); voice assistants such as Amazon's Alexa/Dot and Google Home; advanced power strip (APS); smart thermostat such as the ecobee4; connected devices; smart bulbs or LED smart bulbs; smart plug load controllers; window air-conditioner (AC) controller; single-family homes (SFHs); multifamily units (MFUs); demand-side management; mini-split heat pump; standby load; power consumption; wireless, wi-fi connected; c-wire; smart home

Acknowledgements

The authors thank New York State Energy Research and Development Authority for sponsoring this demonstration. Special gratitude is due to project manager Ryan Moore for his patience and understanding in the contracting delays and programmatic challenges this project encountered.

Con Edison, through its subcontractor ERS, provided all of the measurement and verification as cost share for this project. Amaury De La Cruz at Con Edison played a vital role in seeing the project through and ensuring the quality of the interactions between the research team and the demonstration participants, all of whom are Con Edison customers.

The authors acknowledge the companies Embertec and ecobee for providing substantial discounts on their products for use in the demonstrations depicted in the report.

The numerous site visits would not have been possible without the help of Eric O'Shaughnessy, a National Renewable Energy Laboratory employee based in New York, who provided on-the-ground logistical support and follow-up visits to minimize project team travel from Colorado.

This work was funded through NYSERDA Program Opportunity Notice 3125: Accelerating Availability of Targeted Residential Products.

Table of Contents

List of Figures

List of Tables

Executive Summary

This report summarizes the findings from a collaborative effort between the National Renewable Energy Laboratory (NREL) and Consolidated Edison (Con Edison) to conduct an end-to-end demonstration of practical home energy management system (HEMS) packages that can be easily deployed at scale using technologies that are mature and readily commercially available. The high-level objectives of this demonstration project were to implement simple HEMS solutions for lighting, space conditioning, and plug loads in single-family homes and multifamily units in Con Edison's service territory—and to develop technology transfer strategies based on datasets and insights gained during the implementation process. The demonstration was designed with a particular focus on stakeholder education, to help promote the benefits and savings of HEMS technologies across New York State and achieve wide-scale adoption of proven products and strategies.

While hard energy data were difficult to obtain for reasons described in the report, in a small-scale demonstration with only 15 homes, quantitative savings conclusions would always be anecdotal at best. The most impactful results from this demonstration are derived from observations and challenges we encountered during the actual site visits and subsequent homeowner interactions. Following are key findings:

- Many people have heard of and are interested in smart home products and features but are not generally knowledgeable about the types of products and features that are commercially available. Once they were presented with a few concrete examples of products, people seemed much more receptive to exploring a wider variety of smart home devices.
- Smart thermostats are often not as do-it-yourself or DIY friendly as they may seem. Many homes have legacy wiring or newer air conditioners with proprietary thermostat systems. Future programs may wish to include installation credit as an option, and in addition, work with local trades to have a list of approved and recommended installers.
- Window air-conditioner (AC) controllers have some usability challenges to overcome, but they are very easy to set up and are a reliable measure to incentivize for utility programs that wish to target window ACs.
- Smart light bulbs save significant energy if replacing non-LED bulbs, but otherwise the savings depends on the details of how people use the remote and schedule features and whether they use the dimming function. They are generally easy to install so they are a good candidate for DIY measures. Making sure that existing rebates for LEDs can be used for smart bulbs and offering higher rebates for the more expensive smart bulbs will likely increase uptake. Programs may wish to consider packaging smart bulbs with a voice assistant.

- Voice assistants were the most positively reviewed product in our HEMS lineup, even though they are not inherently energy-saving devices themselves. Bundling the voice assistant with other HEMS devices may be an effective way to introduce more people to smart homes.
- Advanced power strips (APSs) were the most negatively reviewed. While similar products have produced good results in past programs in both USA and Canada, APSs can be challenging for consumers to adopt if they interfere with the way people normally operate their electronics.
- Convenience is a key driver and lack of it is a major deterrent. Many people are willing to purchase a product and learn how to use it if they believe their lives will be made easier.

Finally, the importance of homeowner interactions cannot be overstated. At first many participants seemed overwhelmed by the confusing array of features and apps presented to them, on top of the basic functions of the new HEMS devices. The participants in this demonstration largely reported positive experiences with the smart home devices, but to obtain their buy-in required no small amount of user support and continued engagement.

1 Introduction

The surge in home energy management systems (HEMS) startup companies and product offerings over the past decade coincides with several notable technology and market trends, including the following:

- the growth in web-based cloud computing applications enabling low-cost home energy data storage, analytics, and display
- ubiquitous access to simple user interfaces through broad market penetration of inexpensive touch screens for smartphones and tablets
- an increase in demand for teleworking capabilities, expanding the need for secure home area networks (HANs)
- smart meter rollouts and renewed emphasis on grid modernization
- an increase in embedded sensors and control capabilities in smart home appliances including internet- ready appliances, multi-mode/variable-speed controls and fault diagnostics for space-conditioning equipment, and sophisticated control cycles for major appliances

These trends would indicate that intelligence in residential building systems should be commonplace; yet, HEMS devices struggle to emerge from the niche market. While the slow uptake of some emerging technologies in this space can be attributed to the cost of entry—both real and perceived—and uncertainties around device and platform interoperability, there is a broad class of HEMS products that are generally affordable and usable, at least based on their advertised features and functionalities.

A key barrier to market transformation, then, may be a lack of robust implementation support and stakeholder engagement programs designed to facilitate accelerated adoption.

The scope of this joint endeavor between the National Renewable Energy Laboratory (NREL) and Consolidated Edison (Con Edison) is an end-to-end demonstration of practical HEMS packages that can be easily deployed at scale using technologies that are mature and readily commercially available. The high-level objectives of this demonstration project were the following:

- implement simple HEMS solutions for lighting, space conditioning, and plug loads in twelve single- family homes (SFHs) and twelve multifamily units (MFUs) in Con Edison's service territory
- design and demonstrate technology transfer strategies based on quantitative datasets and qualitative insights gained during the implementation process

The demonstration was designed with a particular focus on stakeholder education to help promote the benefits and savings of HEMS technologies across New York State and achieve wide-scale adoption of proven products and strategies.

2 Demonstration Design and Planning

The project was planned collaboratively by NREL and Con Edison to leverage NREL's expertise in HEMS knowledge and Con Edison's customer network and relationships as well as its experience with conducting measurement and verification (M&V). NREL was primarily responsible for the overall demonstration design; selection, procurement, and installation of the HEMS devices; development of the homeowner engagement strategies to ensure that participants received adequate support to make the most out of their smart home experiences; as well as the data analysis and reporting. Because the process involved extensive interactions with the participants, the project protocol was reviewed and approved by the Central Department of Energy Institutional Review Board (CDOEIRB) to ensure compliance with federal regulations concerning the protection of human subjects.[1] Con Edison and its subcontractor Energy & Resource Solutions (ERS) conducted the participant recruitment and all of the energy monitoring activities. The overall project schedule was as follows:

- Con Edison and ERS recruited participants (late summer 2017).
- ERS conducted the first site visits to obtain participation agreement signatures and install pre-HEMS monitoring equipment (late summer/early fall 2017).
- After at least one month of pre-HEMS monitoring, NREL and ERS conducted the second site visit jointly. NREL installed the HEMS and ERS checked on the monitoring equipment status (fall/winter 2017/2018).
- NREL followed up with participants to answer questions, solicit user impressions, and provide technical support as needed (throughout 2018).
- After roughly one year, ERS conducted the third and final site visits to remove the monitoring equipment (August 2018).

2.1 HEMS Solution Package

A key requirement for this demonstration was that the chosen HEMS products addressed household energy used by lighting, space conditioning, and plug loads. A range of products targeting these end uses were considered for this demonstration.

1 Title 24 of the Code of Federal Regulations, Part 46: https://www.hhs.gov/ohrp/regulations-and-policy/regulations/45- cfr-46/index.html

For single-family homes with central heating and cooling, a smart thermostat offers several attractive advantages over a conventional programmable or non-programmable thermostat. Occupancy detection can help reduce space-conditioning energy use when the home is vacant. Smart thermostats can self-calibrate overtime and learn how long it will take to heat or cool the home to a desired set point. All smart thermostats are connected, which means they can be remotely accessed via smartphones and tablets for scheduling and set-point adjustments. Some devices are equipped with additional wireless remote sensors to improve comfort throughout the home, not just where the thermostat is located. Past program results demonstrate savings of up to 12.5% and 16% for gas (heating) and electric (heating and cooling), respectively, and studies conducted by thermostat manufacturers indicate there is potential to save anywhere from 10–23% on space-conditioning energy costs (e.g., NEEP [2015]; Nest [2015]; ecobee [2013]). In addition, smart thermostats can be a powerful demand-side management tool, as precooling provides a form of residential passive energy storage at a fraction of the cost of battery storage (Robinson et al., 2016).

Many homes, especially multifamily homes, have point-source heating and/or cooling systems such as window-mounted air conditioners (window ACs) or mini-split heat pumps (MSHPs). There are third-party controllers (which function as thermostats but are very different from smart thermostats used on central systems) that are designed to add smart and connected functionalities to point-source equipment. These devices use an infrared (IR) signal to control the window AC or MSHP and also connect to Wi-Fi so they can be remotely accessed via smartphones and tablets for scheduling and set-point adjustments. Schedulers allow for setbacks so that space conditioning is off while people are away but can ensure the space is comfortable when they return home. Some devices even allow for participation in utility demand-response programs.

There is a wide array of smart home lighting products on the market, all aimed at saving energy through the use of LED bulbs combined with scheduling features. In addition to the potential for further energy savings over the incandescent-to-LED conversion, smart lighting enhances convenience. For example, users can schedule lights to turn on before they come home or rely on *house sitting* security features that can mimic occupancy by cycling lights at random intervals when occupants are away. Smart lighting can be incorporated either by installing smart switches that have wireless communication or by changing out individual light bulbs with smart, connected light bulbs.

These two approaches to smart lighting have pros and cons. Switches can be a more robust solution and are cost-effective if homeowners do the installation themselves, but the process can be time-consuming, and if an electrician is needed, the costs can increase quickly. A possible complication is that most smart switches require connection to the neutral wire, and older homes with legacy electrical wiring may not be set up with a neutral. Switches are the preferred solution for light fixtures with numerous bulbs or with non-standard bulb types, where replacing each bulb with a smart bulb may be cost-prohibitive or impractical because of the limited available selection of smart bulbs. On the other hand, smart bulbs offer a comparatively less expensive entry into smart lighting (if one is looking to convert just a handful of independently controlled light fixtures) and are easy to install. A key difference that impacts the user experience is that for smart bulbs to operate on a schedule or be controlled via a wireless app, the wall switch needs to remain in the *on* position. Depending on the user and use case, this could present an undesirable limitation.

To mitigate energy wasted by plug loads, there are numerous plug-load controllers with connected capabilities. Some are plug pass-through devices for controlling individual loads, while others, called advanced power strips (APSs), double as power strips and are designed to facilitate convenient energy savings in the home office and entertainment center where the concentration of consumer electronics is typically high. Pass-through plug controllers can be remotely turned on and off, and schedules can be set up using a smartphone app or website. APSs are typically not connected but employ a variety of smart algorithms to manage active and standby power loss (Earle and Sparn, 2012).

The particular devices used for this demonstration project were selected based on features, prices, availability, and ease of use (and thus likely, consumer acceptance). The products and key functionalities are summarized in Table 1.

2.1.1 Voice Assistant

Consumer engagement and acceptance were key goals for this demonstration, so voice-based artificial intelligence (a *voice assistant*) was included in the HEMS package. As shown in the schematic in Figure 1, all of the HEMS devices employed in this demonstration except for the APS, work with Amazon's Alexa. The Amazon system was selected over other popular options from Google, Apple, and others because Alexa is built into the ecobee4 so that the thermostat functions as a smart speaker.

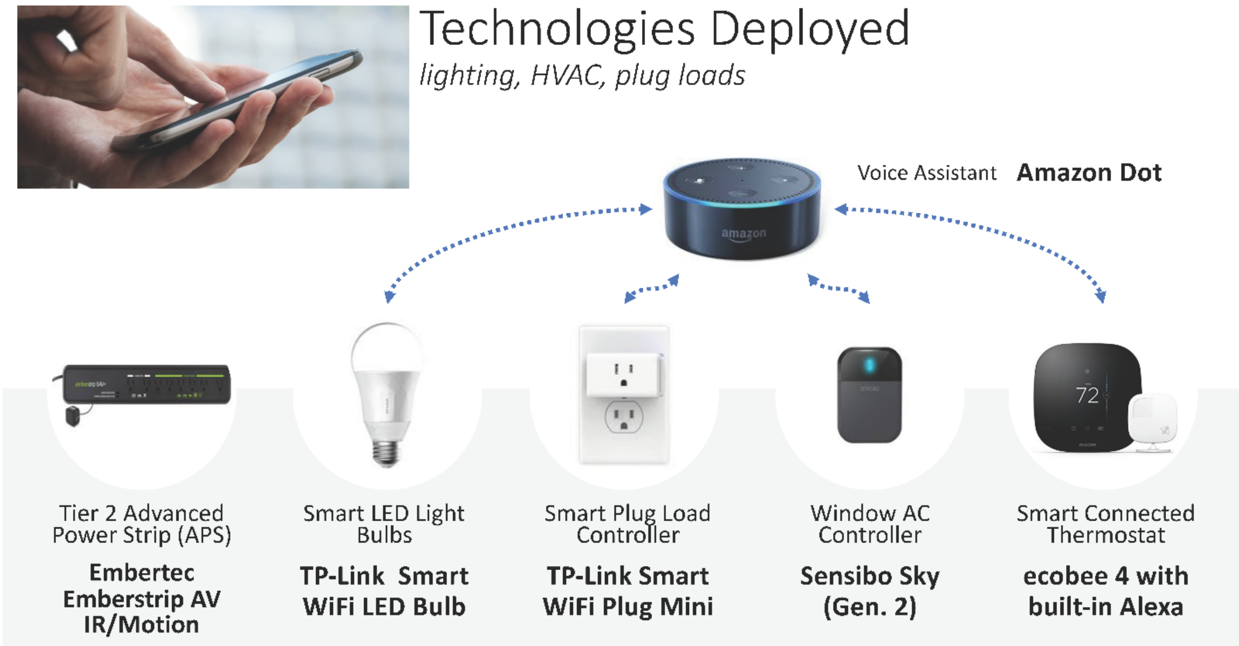
Given the rising popularity of smart speakers this opportunity was leveraged to introduce voice command options for the other smart home products included in the demonstration. Most of the MFUs and two of the SFHs did not receive an ecobee thermostat; those homes received an Amazon Dot smart speaker, which is a more basic version of the Amazon Echo, without the premium speakers.

While not a conventional energy-management tool, voice assistants are being adopted by consumers at a stunning pace. Nearly half of all Americans use some form of digital voice assistant on a regular basis (Olmstead, 2017). While most interactions are with smartphone assistants and most people do not have stand-alone smart speakers (such as Amazon Echo or Google Home) in their homes, this is changing rapidly, as more and more manufacturers of consumer connected devices look to leverage popular voice platforms (Canalys, 2018). The integration of a wide range of connected home devices, from home security cameras to washers and dryers, with voice assistants dominated the smart-home market news at the 2018 Consumer Electronics Show (CES) in Las Vegas.

Table 1. Energy Reduction and Comfort/Convenience Features of Selected HEMS Products

<table>
<tr><td rowspan="2">Space Conditioning</td><td>ecobee 4</td><td>Remote temperature sensors to improve comfort
Wi-Fi connected
Smartphone and web app for remote set-point control
Daily scheduling tool
Home and Away sensing
Vacation mode
Integrated with Amazon Alexa</td></tr>
<tr><td>Sensibo Sky (Gen. 2)</td><td>Wi-Fi connected
Smartphone app for remote set-point control
Daily scheduling tool
Geofencing: can turn on and off based on how far smartphones are from home
Can be controlled via Amazon Alexa</td></tr>
<tr><td>Lighting</td><td>TP-Link Smart WiFi LED bulbs</td><td>Wi-Fi connected
Smartphone app for remote control
App provides on/off or dimming control
Operation can be scheduled based on clock time or sunrise/sunset
Energy usage is tracked in app
TP-Link Bulbs and TP-Link Smart Plugs can be controlled in groups called scenes This feature allows users to turn multiple bulbs and controllers on and off together
Can be controlled via Amazon Alexa</td></tr>
<tr><td rowspan="2">Plug Loads</td><td>TP-Link Smart WiFi Plug Mini</td><td>Wi-Fi connected
Smartphone app for remote control
Operation can be scheduled based on clock time or sunrise/sunset
Away mode will turn plug load on randomly during preset period (commonly called house sitting)
Timer feature to set state of plug at the end of the timer period
TP-Link Bulbs and TP-Link Smart Plugs can be controlled in groups called scenes This feature allows users to turn multiple bulbs and controllers on and off together
Can be controlled via Amazon Alexa</td></tr>
<tr><td>Embertec Emberstrip AV IR/Motion</td><td>Power-saving outlets will automatically shut off supply power when devices are turned off
Controlled outlets will also be turned off when there has been no activity detected (based on motion or remote-control activity) for a certain length of time (configurable to be 1,2, or 8 hours)
Always on outlets for DVR, router, or other devices that should not be turned off
Bluetooth connected (when paired smartphone is in range)
Smartphone app shows power consumption of controlled outlets
Smartphone app can also be used to turn off controlled outlets</td></tr>
<tr><td>Voice Assistant</td><td>Amazon Dot</td><td>Wi-Fi connected
Provides voice control for all compatible devices
Smartphone app can be used to group devices together for control</td></tr>
</table>

Figure 1. HEMS Devices Selected for this Demonstration Integrate with Amazon Alexa Voice Assistant (except APS)



2.2 Recruitment

Recruitment was conducted by Con Edison and its subcontractor ERS. A list of eligibility criteria was developed by NREL and sent to Con Edison to use as a screening tool for selection. These criteria are summarized in Table 2.

The flyer in Figure 2 was emailed to prospective participants who had previously expressed interest in other energy efficiency programs run by Con Edison. The prospective participants had received rebates for new central or window AC systems but were not enrolled in Con Edison's smart thermostat or smart window AC program. Interested customers were invited to fill out a brief online survey to help us determine their eligibility for this study. The survey questions are shown in Table 3.

The first round of recruitment emails went out with only a contact phone number and did not provide an email option for interested respondents. In the second and third rounds an email address was included, which resulted in many more responses. Once people completed the survey, they were contacted by ERS for a follow-on conversation to determine eligibility and confirm interest. Initially, the target pool included only Brooklyn and Queens but because of the challenge with recruiting a sufficient number of participants from these areas, the search area was expanded to include Westchester County.

Recruitment proved to be a major challenge. A total of 5,818 emails were sent to prospective participants in three segments. The incentive offered to install the HEMS devices—which participants could keep—was, depending on the home, equivalent to roughly a $500 value, an amount that we anticipated would draw many more people. After ERS conducted phone screens there were a total of 19 prospective participating households. The initial goal had been to obtain 12 SFHs and 12 MFUs; however, because the project had already suffered substantial delays in getting started, it was decided that the demonstrations would proceed with the 19 confirmed households.

It must be noted that the combination of the online survey and the subsequent screening phone calls failed to address adequately all of the elements in our initial participation criteria, most notably the ecobee compatibility question. This led to some implementation challenges, as described in Section 3.

Table 2. HEMS Demonstration Eligibility Requirements

All Homes	• Households must have a minimum of two occupants. Families of three or more occupants are preferred.
	• Households must have a home Wi-Fi network that can be used with the HEMS devices.
	• Home must have at least one entertainment center consisting of the following:
	  o one television
	  o at least two other controllable appliances* such as the following:
	    ▪ DVD/Blu-Ray player
	    ▪ VCR
	    ▪ stereo amplifier
	    ▪ game console
	    ▪ streaming device (e.g., Roku, Apple TV)

Single-Family Homes (SFH)	• Home must have a central ducted AC system that is compatible with the ecobee4 thermostat: ww.ecobee.com/compatibility/ • Preferred: central heating system as well (so that thermostat will control both heating and cooling system).
Multifamily Units (MFU)	• Home has at least one window AC unit that does not currently have smart controls.
Additional Requirements	• Someone from the household will need to be present for the installation, check-up, and removal of M&V equipment and installation of HEMS devices. • Occupants must be willing to respond to an initial questionnaire. • Occupants must be willing to respond to a second questionnaire at demonstration closeout, which will include basic questions about their experience with the HEMS. • Occupants must be willing to have their electricity use monitored by ConEd during the demonstration period. No personally identifiable information will be reported in the test results.

* DVRs or TiVo-like video recorders will be plugged into "always on" outlets so their functionality will not be affected. A DVR should not be counted as a controlled appliance.

Figure 2. Recruitment Flyer Email

Con Edison would like to understand the impact of home automation technology on residential energy usage. We've partnered with the National Renewable Energy Lab (NREL) on this energy study, and we hope you'll consider helping us too.

In exchange for your participation in this valuable energy study we're offering you a free home energy management system (HEMS). All we ask is that you take part in a short survey, and that you assist us with monitoring your home's energy usage throughout the duration of the study. We assure you that any data gathered will be kept confidential.

By taking part in this valuable energy study you're taking an important step towards improving your home's energy efficiency, which can lead to cost-savings. We greatly appreciate your time and effort to help Con Edison improve the electric grid.

If you would like to participate and to determine your eligibility, please click here to complete a 10-question survey

The equipment includes a smart air conditioner controller, an advanced power strip, smart light bulbs, plug controllers, and a central voice-activated control unit. All installed equipment will be yours to keep after the study has ended. The study will involve metering your home energy use for the remainder of the summer without the HEMS, then installing the HEMS equipment and continuing the metering for an additional ten months.

The study will be performed by ERS, an energy measurement firm that has been contracted by Con Edison. During the first visit (which should take no more than 2 hours), ERS will complete a survey of your heating and cooling systems, home entertainment equipment, and lighting systems and will place unobtrusive devices (data loggers) on the impacted equipment to understand energy usage patterns.

At the end of the summer metering phase in October, NREL and ERS will supply, install, and configure a new smart thermostat with remote sensors, an advanced power strip to control your home entertainment equipment, smart lightbulbs, and remote plug controllers on other equipment. Additionally, a central voice-activated control unit will be installed. ERS will return once during the metering period to check on the loggers, and again at the end of the metering period to collect the loggers. The total length of the study will be approximately one year.

Questions for Con Edison? Reach
Amaury De La Cruz at 212-460-3093
Monday - Friday, 8am – 4pm

Table 3. Eligibility Survey Questions Used for Screening Prospective Participants

1. Are you willing to commit to four two-hour visits from our team over the course of the next year? An adult must be present during each visit.
2. Do you own or rent the place where you live?
3. How would you describe where you live?
   - freestanding single-family building
   - single-family attached (e.g., row house)
   - part of all of a duplex
   - condo or apartment in a larger multifamily building
   - other (please specify):
4. Do you have a home Wi-Fi network?
5. How many people live in your home?
   - 1
   - 2-3
   - 3+
6. Do you use air-conditioning to cool your home?
   - Yes, central air
   - Yes, window air-conditioners
   - Yes, some other type of air-conditioner:
   - No
7. Does your current air conditioner have a Wi-Fi enabled" smart" control or thermostat?
8. Do you have at least three light fixtures that would fit a classic pear-shaped (A19) bulb and not currently have a dimmer control?

There were four *opt-outs* over the course of the demonstration:

- One participant was disappointed to learn that his existing space-conditioning system was not compatible with the ecobee4 thermostat. The smart thermostat was the primary motivator for him to participate in the program, so he chose to opt out of the program.
- One participant was informed that the control board at his air handler would need to be upgraded in order to install the smart thermostat. Although he was offered this upgrade (which would be completed by a service technician) free of charge, he was less than enthusiastic about the prospect of having to wait two to three weeks to complete the process and decided to opt out of the program.
- One participant was irritated with the connectivity issues encountered during the smart bulb installation and opted out of the program immediately.
- One household had the pre-HEMS monitoring equipment installed on the first site visit, but subsequently became unresponsive to the project team's efforts to contact them to schedule a HEMS installation visit. Communication was finally reestablished toward the conclusion of the demonstration program; at that point it was deemed not practical to schedule an additional visit to install the HEMS.

In the end there were a total of 15 households that participated in this demonstration, and their locations by zip code are illustrated in Figure 3. (There are two MFU sites that are located in the same neighborhood, resulting in two red markers on top of one another.)

Figure 3. Map of the Demonstration Sites with the Blue Houses Representing Single-Family Homes and the Red Houses Showing the Multifamily Units

Source: Google Maps

Table 4. Energy Measurement and Verification Overview

	Physical Quantity	Metering Strategy	Logger Type		Interval
Space conditioning	Temperature, Relative Humidity	Wall-mounted meters by thermostat and remote sensors	Onset HOBO U12 Temp/RH meter		15 min.
	Central HVAC power consumption (AC compressor, blower motor)	Meter at circuit breaker panel	Onset HOBO UX120-006M		5 min.
	Window AC power consumption	Plug load logger	Onset HOBO UX120-018		5 min. average
	Blower motor on/off state	Use blower motor on/off state to approximate power if panel access is not possible.	Onset HOBO UX90-004M		State change
Lighting	Light on/off state	Monitor operating hours for hard-wired light fixtures. Use light pipe attachment to mitigate interference from other light sources.	Onset HOBO UX90-002M		On/off % per hour
	Light level	For hard-wired fixtures where dimming is desired, install near light to determine approximate brightness level for dimming.	Onset HOBO U12-012 light level meter		5 min.
	Light power consumption	For plug-in fixtures, install plug load logger to determine operating power. To be translated to both on/off and dimming % after testing.	Onset HOBO UX120-018		5 min. average
Plug loads	Entertainment center and plug load power consumption	Install in line with existing power strip or power cord.	Onset HOBO UX120-018		5 min. average

2.3 Measurement and Verification Strategy

M&V was provided by Con Edison through ERS. The basic strategy was to install the monitoring equipment at least one month prior to the HEMS installation and then compare the pre- and post-HEMS energy consumption and equipment usage patterns. Ideally several months of data before HEMS devices are installed would be desired; however, because of a series of contracting delays and programmatic challenges with getting the project off the ground and participants recruited, a compressed pre-HEMS monitoring period was in many cases necessary. The metering strategy and sensor types are summarized in Table 4.

3 Implementation and Results

3.1 Site Visits

There was a minimum of three site visits for each participating household. ERS was present for all three: The first and third were for monitoring equipment commissioning and decommissioning, respectively, and the second site visit was used to check the status of the HOBO loggers. NREL installed the HEMS devices on the second site visit at each home.

The HEMS installation site visit consisted of a detailed orientation of the smart home products for the participants. First, the homeowner was asked to download all of the relevant smartphone apps and instructed to create an account for each one. Meanwhile, NREL installed all of the HEMS hardware. For plug-load controllers and smart bulbs, the homeowner was consulted to determine the most convenient location. Once all the devices and apps were installed, NREL configured the devices to connect to Alexa. Each app was tested and demonstrated to the homeowner. For reference, NREL prepared and provided each homeowner a Quick Start Guide (see Appendix) that describes the connected features and functionalities of each device and corresponding smartphone app.

3.1.1 Thermostat Incompatibility

A major unexpected complication was that, for the majority of the SFH participants, upgrading their thermostat to the ecobee4 smart thermostat was either complicated or not possible. Of the nine SFHs in the demonstration, only three homes had both air-conditioning and heating systems that were compatible with the ecobee. Many of the homes had separate thermostats for heating and cooling, and in many of these cases only the heating system was compatible with the ecobee. In addition, five of the homes had legacy wiring systems and/or lacked a common wire, and it was necessary to schedule a follow-up visit with an HVAC technician to complete the installation. In the end, a total of 11 ecobee thermostats were installed in eight homes (seven SFHs and one MFU), with only three ecobee thermostats controlling a central AC.

3.2 Energy Use Results

The demonstration period ended in August 2018, and subsequently all of the HOBO data loggers were collected by ERS staff during the final site visit. The data from those meters were provided to NREL soon after the loggers were collected. The data from each house was analyzed to capture the change in usage after the HEMS devices were installed. For practical reasons, the measurement type used to determine the energy consumption of each device varied among homes and occasionally even among the same device type within a single home.

3.2.2 Dataset Challenges

In order to determine the energy savings for the HEMS devices, baseline data before the HEMS installations were collected for each device and the same data were collected after the HEMS installations. The project experienced a number of setbacks that affected our ability to determine energy savings for each device. A summary is given in the following section.

3.2.2.1 Causes of Incomplete Data:

- Air conditioner control was one of the key technologies, so we planned to install all the monitoring equipment in the summer of 2017. Due to delays related to recruitment, monitoring equipment was not installed until the fall of 2017. In some cases, we were able to capture some pre-HEMS cooling data, but there were more homes that did not have any.
- Some loggers ran out of battery or memory before the demonstration ended. All of the T&RH loggers ran out of memory before the end of the demonstration. In some cases, the T&RH data extended into the beginning of the summer of 2018, allowing us to capture a useful sample of post-HEMS cooling data, but in other cases, the logger filled up and stopped collecting data in the spring of 2018 before cooling was needed. A handful of other loggers' batteries expired before the end of the demonstration.
- In some homes with multiple space-conditioning systems, not all systems had usage monitoring (current or motor sensors) installed. Ecobee thermostats and Sensibo controllers were installed for all compatible systems in a home but data were not always available for determining whether the controllers provided any energy saving or comfort benefits to the homeowners.
- T&RH loggers were generally installed in common areas, even in MFUs with multiple window AC units. In the future, T&RH should be monitored in each room when there is a window AC or a MSHP.
- Plug-load meters were generally installed on power strips with large numbers of devices plugged in. While that was appropriate for entertainment centers where the APSs were going to replace the standard power strips; however, it was not appropriate for monitoring plug loads to be controlled by the smart plugs. In most cases the plug-load meters had to be relocated once the homeowners were aware of the capabilities of plug-load controller.

3.2.3 Smart Thermostats

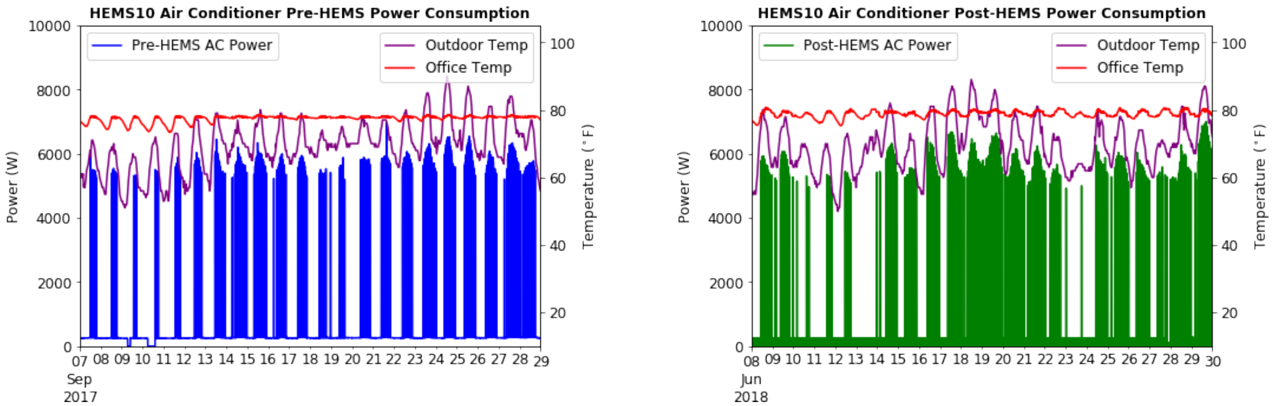
In order to assess the impact of the smart thermostat in the home, ERS installed T&RH sensors near each thermostat. The air conditioner use was monitored separately, either by measuring current draw in the breaker panel for the outdoor condenser or by measuring the motor run-time for the condenser. Since outdoor weather is the main driver for air-conditioner power consumption, we also included hourly weather data from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information in our analysis (NOAA, 2018). Weather data collected at JFK Airport in Queens was used for all the homes in that borough, while weather collected at the Westchester Airport was used for analyzing data from homes in Westchester.

The monitoring equipment was installed in the fall of 2017; therefore, in many homes, no pre-HEMS air-conditioner data were available to compare to the post-HEMS data. As a result, data analysis related to the smart thermostats was limited. In the homes where pre- and post-HEMS data were available, we looked for a period of days where the air conditioner was used before the smart thermostat was installed and calculated the average indoor and outdoor temperatures. Then we looked for a period in the following summer (after the thermostat was installed) with the same duration and outdoor temperature. Once the pre- and post-HEMS periods were selected, the daily energy use or run-time of the air conditioner was calculated.

Some example results are shown in the figures below. Figures 4a and 4b show one house where the smart thermostat appears to have led to a small decrease in energy use. The daily energy use dropped 4% between the 22-day pre- and post-HEMS periods. (In these and subsequent figure captions, HEMSxx refers to the numbered label assigned to each site.) The savings appears to be coming from a temperature set back during the day. The average indoor temperature increased slightly (by 1.5°F) and there is a noticeable diurnal temperature swing in the post-HEMS timestreams.

Figures 5a and 5b show results from another house where the usage of the air conditioner increased after the smart thermostat was installed. The average daily run-time for the air conditioner increased from 2.7 hours per day before the smart thermostat was installed to 3.3 hours per day after, representing a 22% increase in run-time. This also corresponded to a 2°F drop in average indoor temperature, suggesting that the homeowners may have been more comfortable even if there was an increase in energy use.

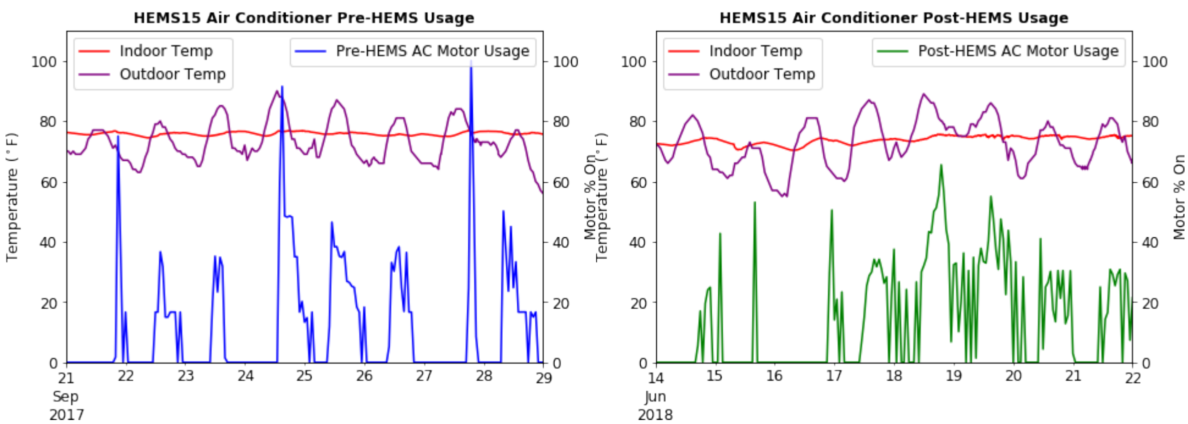
Figure 4. Comparison of Air-Conditioner Owner Consumption, Indoor Temperature, and Outdoor Temperature Before and After Smart Thermostat Installation in HEMS10



(a) Air conditioner performance before smart thermostat installation

(b) Air conditioner performance after smart thermostat installation

Figure 5. Comparison of Air-Conditioner Power Consumption, Indoor Temperature, and Outdoor Temperature Before and After Smart Thermostat Installation in HEMS15



(a) Air conditioner performance before smart thermostat installation

(b) Air conditioner performance after smart thermostat installation

3.2.4 Window AC Controllers

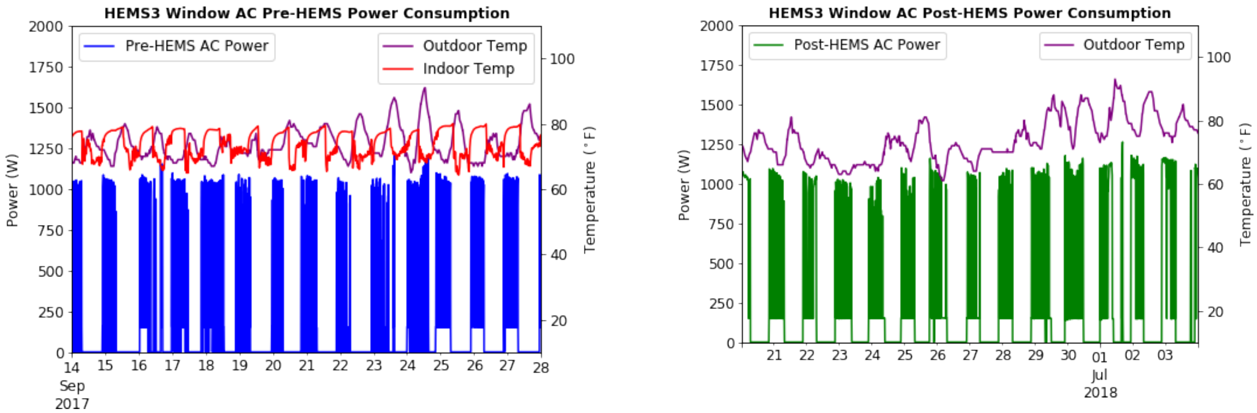
The instrumentation used to monitor the window ACs was similar to instruments used for central air conditioners. T&RH sensors were generally installed in the common areas of MFUs, where window ACs were typically located. In most cases, a plug-load power meter was used to measure the power consumption of the window AC, although in a few cases a motor run-time sensor was used instead. Outdoor weather was also used in the window AC analysis, using the same hourly NOAA data from JFK Airport and Westchester Airport for locations in Queens and Westchester, respectively.

All of the monitoring equipment was installed in late summer and early fall of 2017, which was similar to the homes with central air conditioning; few homes with window ACs had any pre-HEMS data to use for analysis. The analysis process was the same between the central air conditioners and the window ACs. We looked for several days (or more) where the window AC ran before the controller was installed and calculated the average indoor and outdoor temperatures. Then we tried to find an equivalent period of time in the following summer with a similar average outdoor temperature over the same number of days. After the periods for pre- and post-HEMS analysis were chosen, each window AC's daily energy use or run-time was calculated for each period.

Some results from the window ACs are shown in Figure 6. The first pair of graphs, Figures 6a and 6b, are from a home with two window ACs, one in the living/dining room area and one in the bedroom. The living room window AC was not used at all during the pre-HEMS phase. The results below are from the bedroom window AC. However, the T&RH sensor was located in the dining room near the main window AC unit, so the indoor temperature that was measured is not directly influenced by the bedroom unit. Also, the logger used to measure T&RH ran out of memory before the cooling season began in 2018, so there are no indoor temperature data for the post-HEMS period.

For this window AC unit, the daily energy use increased by about 15% between the pre- and post-HEMS analysis periods. It is hard to know what drove the increase in energy use because we do not have indoor temperature data from the bedroom. Most likely, the homeowners were able to keep their bedroom more comfortable with the improved controls, a result seen in other homes.

Figure 6. Comparison of Bedroom Window Air-Conditioner Power Consumption, Indoor Temperature, and Outdoor Temperature Before and After Controller Installation in HEMS3



(a) Window air conditioner performance before controller installation

(b) Window air conditioner performance after controller installation

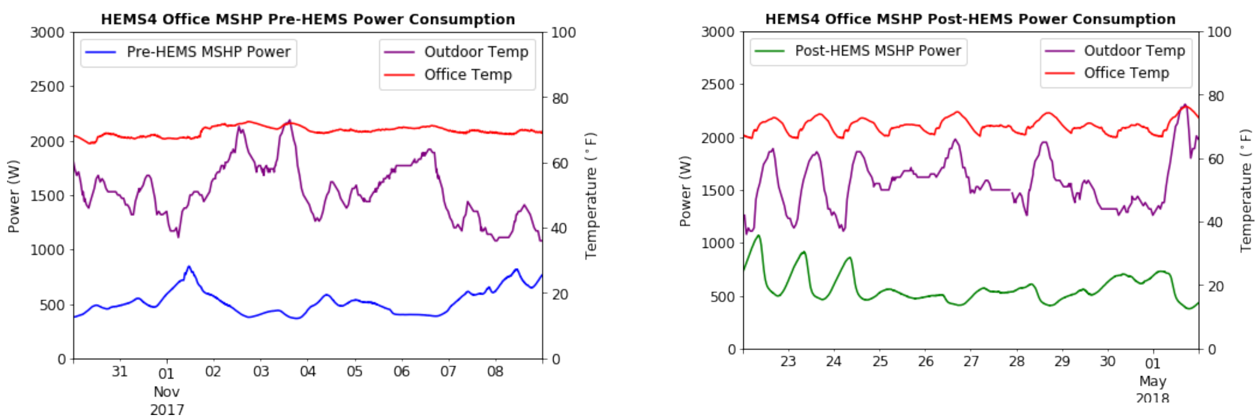
Most of the single-point cooling equipment we encountered were window ACs, but one participating home had a MSHP located in a large home office that did not get sufficient heating and cooling from the central system. We installed the Sensibo window AC controller on the MSHP and compared the energy use of the MSHP in heating mode in the fall and spring. In this case, the MSHP used slightly more energy per day (11% increase) and there was an average daily indoor temperature increase in the office by 1.55°F, indicating improvement in comfort if not a reduction in energy use.

3.2.5 Lighting

There were two different types of sensors installed to monitor light usage: an on/off light sensor and a light level sensor. The on/off light sensors did not provide any insight into whether the occupants took advantage of the dimming capabilities of the smart LED bulb. On the other hand, the light level sensors are susceptible to noise from ambient light. Also, while the light-level sensors can detect changes in light level due to dimming, it is difficult to correlate light level to energy use, especially in fixtures with multiple bulbs.

Light sensors were installed in fixtures around the house that were used frequently and/or where the homeowner wanted dimming capabilities. A total of six smart LED bulbs were installed in each house. Since lighting usage varies depending on the time of year and length of daylight, we looked at the light usage during the pre-HEMS period and then looked at the same duration immediately following the installation of the smart LED bulbs, so that the periods were roughly the same in terms of number of daylight hours per day. Most of the homes had their HEMS equipment installed during the first week of November, which also happened to be the same week that daylight saving time (DST) ended. The time change may be responsible for some of the increase in light usage per day. Overall, an average increase of about an hour per day was observed across all on/off light sensors. There were far fewer light level sensors installed, but we saw an average decrease of about 500 lumen-hours per day.

Figure 7. Comparison of Office Mini-Split Heat Pump Power Consumption, Indoor Temperature, and Outdoor Temperature Before and After Controller Installation in HEMS4



(a) Mini-split heat pump performance before controller installation

(b) Mini-split heat pump performance after controller installation

A sampling of results is presented in the following figures. Figure 8 shows the light level measured at the dining room fixture in HEMS10. The fixture originally had two 10 W CFL bulbs installed. After the dimmable LED bulbs were installed, the average lumen-hours per day dropped by about 30%, although that may not mean that the LED bulbs were dimmed by 30% or that they use 30% less than their rated power consumption of 8 W.

Figure 8. Light Level Data from the Dining Room Fixture in HEMS10.

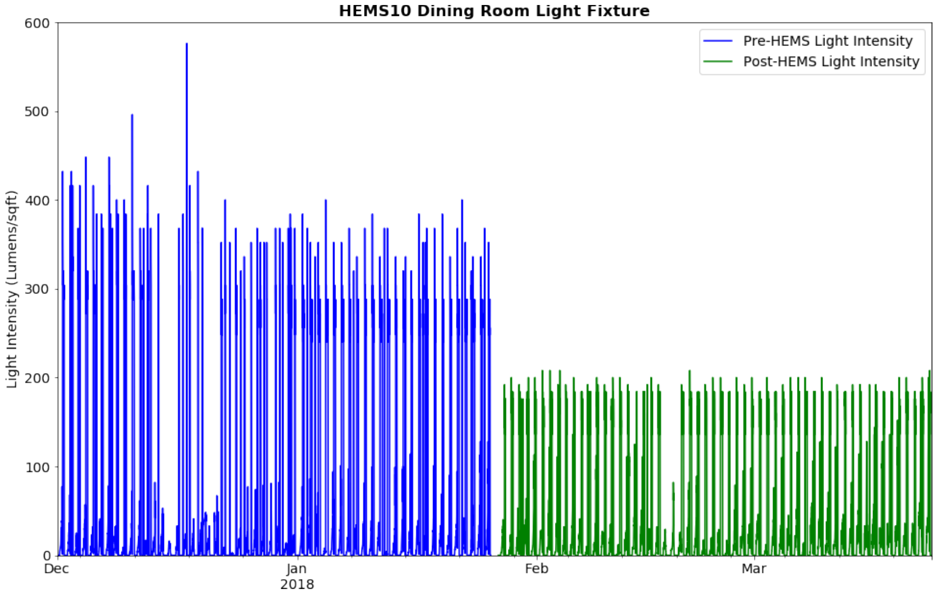


Figure 9 shows a case where the average daily hours of usage dropped after the smart LED bulbs were installed. This data came from a lamp in the living room of HEMS3 that originally used a 100 W incandescent bulb. The daily usage dropped from 1.7 hours per day before the smart LED bulb was installed to 1.3 hours per day. Although the decrease in usage was small, the increase in efficiency by switching to the LED bulb meant that the daily energy savings was over 90%. The savings could be even greater if they dimmed the LED light further.

Figure 9. Daily Light Usage for a Living Room Lamp in HEMS3

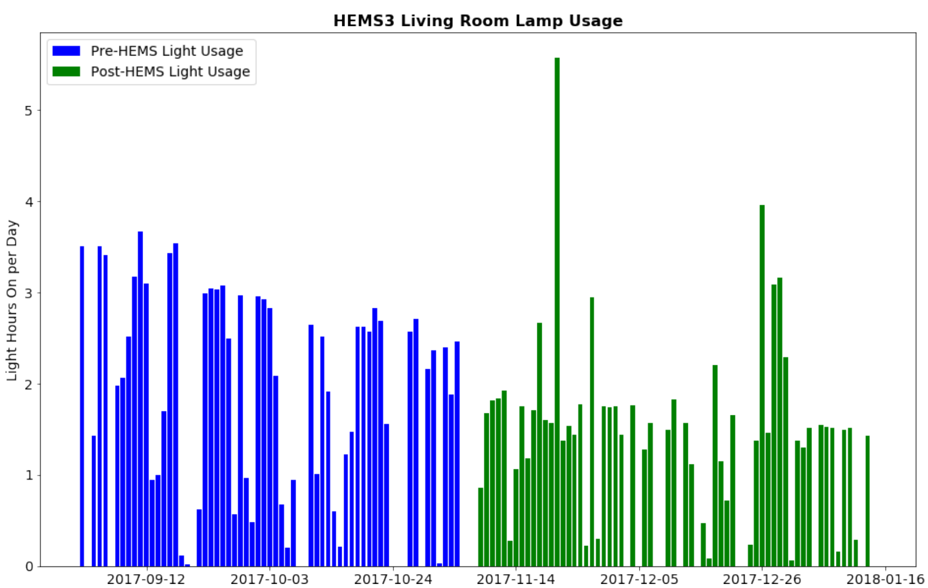
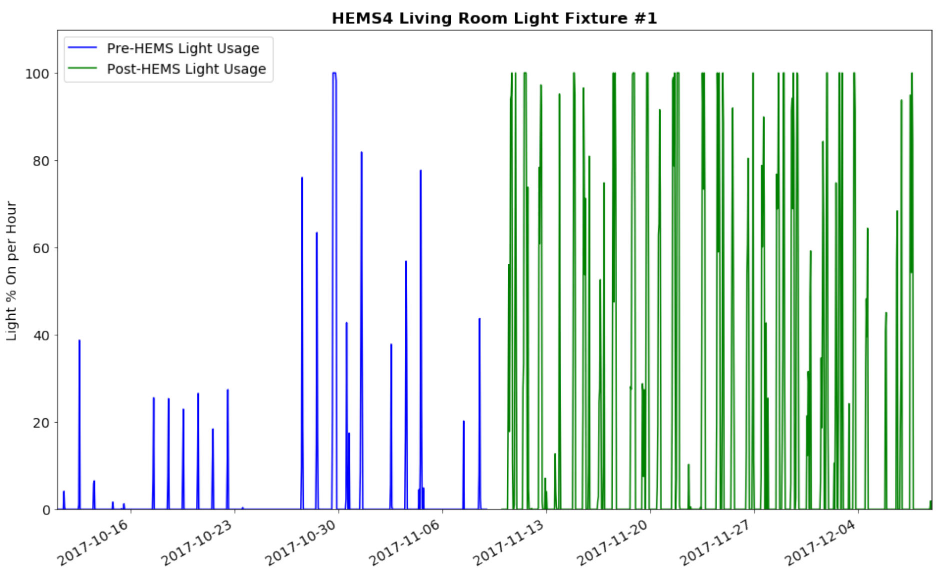


Figure 10, the last graph from the light results, is a case where the light usage went up after the LED bulb was installed. These results are from a living room lamp fixture that originally used two CFL bulbs (26 W and 13 W). This case is more dramatic than most, since the daily usage increased from about 0.6 hours per day to 4.1 hours per day after the smart LED bulb was installed. The impact on the daily energy use is moderated by the fact that the LED bulbs improved the efficiency of the lamp, but the daily energy use nearly tripled. It is possible that the homeowner started scheduling the bulbs in this fixture to turn on daily (although the usage pattern does not appear to be regular) or that they used the app or Alexa to the turn the light on more frequently. This was a greater increase in usage than was typical, but we did see an overall increase in daily light usage among the lights that were measured with an on/off sensor.

Figure 10. Hourly Light Usage for a Living Room Lamp in HEMS4



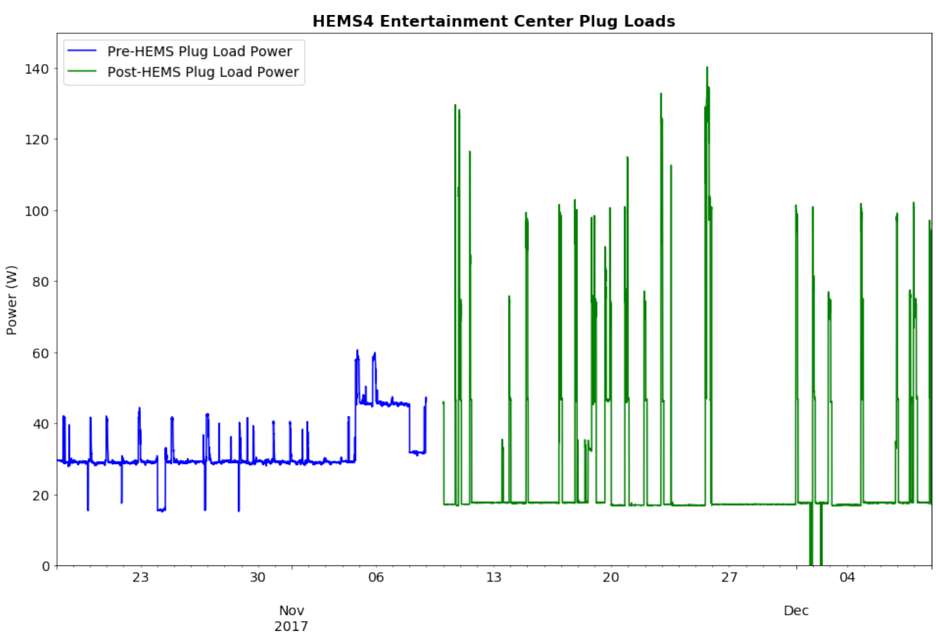
3.2.6 Plug Loads

Plug-load power meters were installed in between the plug load (or power strip) and the wall outlet. There were two different types of plug-load controllers that were installed in each home: an APS to replace the standard power strip in an entertainment center and a plug-load controller that can be used to more easily control power to any individual plug load. The plug-load power data were reviewed for the pre-HEMS period and for an equivalent period of time after the plug-load controllers were installed. Plug loads are not expected to have much seasonality but this analysis plan would avoid seasonal impacts as much as possible.

In a number of cases, the plug loads that were connected to the power meter were not the same plug loads that were ultimately connected to the controller and power meter. In some cases, the APS had fewer total outlets or not enough uncontrolled outlets to accommodate all the devices plugged into the original power strip. The individual plug-load controllers were often installed on different plug loads than were originally monitored once the homeowners understood what the plug-load controllers could do. We were surprised to find that in many households it was challenging to identify plug loads that were suitable for controlling either on a schedule or via voice commands.

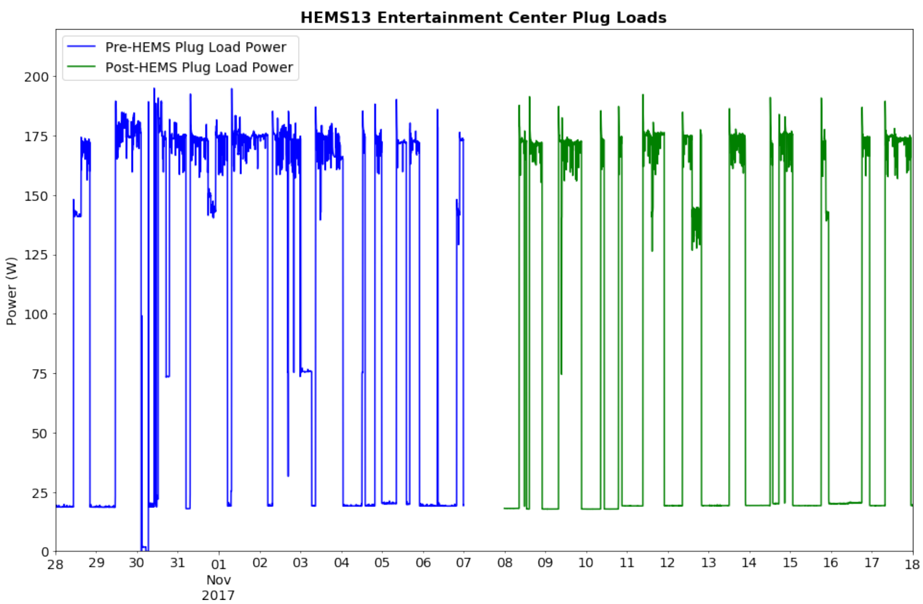
Figure 11 is a clear example of a mismatch between the loads that were monitored before and after the APS was installed. In such a case it is impossible to know if the controller helped the homeowners save energy at the entertainment center. Unfortunately, there were several homes that fell into this category, but we opted to err on the side of ensuring that the most suitable loads were plugged into the APS, regardless of what was being monitored prior to the HEMS installation visit. This decision maximized potential benefit for the participants, even if it cost the project reliable pre- and post-HEMS energy data for analysis.

Figure 11. Power Consumption of the Entertainment Center Power Strip in HEMS4



In contrast, Figure 12 shows power data from an entertainment center where the motion-sensing APS appears to have helped to save energy by turning some devices off. The daily energy use of the entertainment center decreased by about 25% after the APS was installed, which is consistent with other national studies on Tier-2 APS that use motion sensing. Another case where there was an obvious impact from the plug-load controller is shown in Figure 13. At this house, a diffuser candle was connected to the plug-load controller and apparently used to be on for days at a time. After the HEMS was implemented, the diffuser looks to have been set on a schedule or turned off more frequently. The change in usage pattern resulted in a 50% drop in daily energy use by the diffuser.

Figure 12. Power Consumption of the Entertainment Center Power Strip in HEMS13

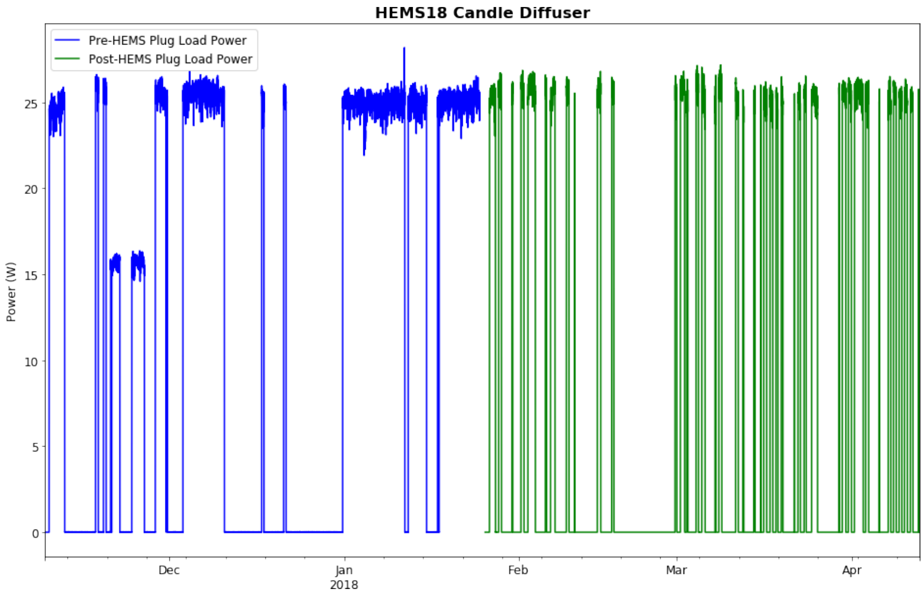


Overall, results for the plug-load controllers were largely inconclusive. In many cases the plug-load meter was installed on a different end use between the pre- and post-HEMS periods, and in other cases there was no change in the plug loads' energy use pattern, indicating that the plug-load controller was probably not used to set up schedules or control via voice commands.

3.2.7 Standby Loads for HEMS Devices

All of the HEMS devices installed include some type of communication that requires constant power consumption. While this standby load is small, it can add up over time.

Figure 13. Power Consumption of a Diffuser Candle in HEMS18



The standby loads for the HEMS devices were measured in NREL's Systems Performance Lab—a laboratory with residential building infrastructure and high-accuracy power meters on every circuit. Each device, except for the ecobee thermostat, was plugged into a sub-metered outlet and connected to the Wi-Fi network in the laboratory. The Emberstrip AV IR/Motion APS was connected to a smartphone over Bluetooth during the test period. The device was left idle for five minutes and the average power consumption over that time is given below in Table 5. The standby power consumption for the ecobee4 thermostat was not measured at NREL but was reported to ENERGY STAR® for their Smart Thermostat certification (ENERGY STAR, 2017). NREL's laboratory is not currently set up to measure thermostat power consumption separately from the air handler, which powers the thermostat.

Table 5.Standby Power Consumption for HEMS Devices

Device	Standby Power (W)
ecobee 4	1.2 *
Sensibo Sky	0.4
TP-Link Smart Bulb	0.4
TP-Link Smart Plug	1.0
Emberstrip AV IR/Motion	1.1
Amazon Dot	1.9

* ecobee standby power was not independently measured.

3.3 Surveys and Resident Feedback

From the outset, the focus of this demonstration was centered around developing strategies for homeowner engagement. With a small number of study samples (24 homes were planned initially, but in the end, we had 15 homes), the measured data on energy use characteristics were intended to provide supporting evidence for the more subjective information collected through participant feedback and surveys. To this end, two written surveys were administered: one prior to the HEMS installations and one at the conclusion of the demonstration, as the monitoring equipment was being removed. Several participants opted to email their responses back to us, but the majority filled out the paper copy during the site visit. The survey questions are listed in Table 6.

Following are key takeaways after aggregating the survey responses:

- The key motivating factors for participating in this demonstration were enhanced convenience and the potential for saving energy and/or money through smart energy management. A relatively small number of participants cited improved comfort as a key reason.
- Both before and after the demonstration, every respondent expected that these products will or did help save energy.
- The vast majority of respondents did not have any smart home products prior to the demonstration. When asked about their familiarity with smart home products, most respondents were not able to name even some of the more basic features of popular smart home products. This changed as a result of the demonstration and people became much more aware of available functionalities.
- The main reason people did not already have smart home products in their homes is that they were confused about the smart homes space: available products, what the products are capable of, and how to select, install, and use them.
- In the post-HEMS survey, many participants reported they have either already purchased additional smart home devices or planned to do so as a result of this demonstration.

Table 6. Pre- and Post-HEMS Surveys

Pre-HEMS Questions	Post-HEMS Questions*
1. What is your primary reason for being interested in trying these Home Energy Management System (HEMS) products? Is it convenience, improved comfort, energy savings, or some other reason? 2. Do you own any other HEMS (or 'smart home') products already? If so, what? 3. Have you considered buying products like these? If you haven't purchased any yet, why not? 4. Even if you don't already own any smart lighting, smart plug-load controllers, or smart thermostats, are you familiar with what they can do? Can you list some features that you have heard of? 5. Do you expect that these products will help you save energy? 6. Do you expect that you might purchase additional HEMS devices to add to your smart home after being introduced to HEMS through this project?	1. Please give us a few comments on each of the products that were installed in your home during this demonstration. We are interested to know how you used each device, whether you found them convenient or difficult to use, or any other feedback you have for us. For example, did you set up a schedule on the app? Did you control it manually using the app or through voice commands using Alexa? o TP Link Smart LED Light Bulbs o TP Link Smart Plug-Load Controllers o Amazon Alexa Voice Assistant (either via your ecobee or the Amazon Dot) o Embertec Emberstrip Advanced Power Strip o ecobee 4 Smart Thermostat (if applicable) o Sensibo Sky Smart AC Controller (if applicable) 2. Please tell us about the smart phone apps. Which apps did you use, if any? Did you use the schedule feature in any of the apps? Did you find the apps to be user-friendly? Let us know if you have specific feedback, positive or negative, on the different apps. 3. Did you learn anything new about smart lighting, smart plug load-controllers, or smart thermostats, through participating in this project? 4. Do you think these products have helped you save energy? 5. Do you expect that you might purchase additional HEMS devices to add to your smart home after being introduced to HEMS through this project? Would you recommend them to a friend?

* Participants enthusiastically embraced the voice assistant. Being able to turn things on and off using Alexa was a very popular feature.

4 Conclusions and Recommendations

While this project presented challenges in obtaining hard energy data, in a small-scale demonstration with only 15 homes, quantitative savings conclusions would always be anecdotal at best. The most impactful results from the demonstration are derived from observations and challenges encountered during the actual site visits and subsequent homeowner interactions.

Smart thermostats are commonly marketed as do-it-yourself, or DIY, but are not practical DIY installations for many people. The most common issue is the lack of a common or *C-wire*, but there are many other situations where a smart thermostat cannot be installed. Even within this small demonstration, a variety of configurations were encountered that were not immediately compatible with the ecobee smart thermostat, including the following:

- no C-wire
- wireless thermostat(s) proprietary to existing air-conditioner unit
- master/slave thermostats
- multiple zones
- proprietary thermostat wiring

In some of these cases, a service technician was able to follow up and run new wires, install a device to mimic the C-wire, or replace the control board on the air handler to make the smart thermostat compatible, but these solutions can hardly be considered DIY for most people. If a homeowner were paying to make the upgrade, the cost of hiring a professional to install the smart thermostat could easily double or triple the price of the thermostat itself.

By recruiting from a pool of people who had received rebates for air-conditioner upgrades but who weren't already participating in a smart thermostat program, this demonstration may have been inadvertently biased to recruit homes with systems that were challenging to upgrade to the ecobee. While survey responses indicated that the smart thermostat served as a powerful participation incentive, subsequent conversations with some of the homeowners suggest that the compelling element was not necessarily the free thermostat itself, but rather the prospect of having one professionally installed and set up. Ecobees and several other smart thermostats are designed to be DIY, but if a home's system is either incompatible with this type of thermostat or if the installation is more complex and requires a service professional, those people may have had additional motivation to participate in this demonstration—to solve their smart thermostat upgrade problem.

Because installation challenges were significant, future programs may wish to include installation credit as an option, and in addition, work with local trades to have a list of approved and recommended installers. For this project, identifying service technicians willing to visit the sites and complete the ecobee installations was difficult and time-consuming. (In the end we found one company in Brooklyn and one in Westchester willing to undertake the job.)

Window AC (or MSHP) controllers had fewer compatibility problems than the smart thermostats but there were notable installation complications to suggest that these products will continue to evolve. For example, the Sensibo requires a remote control to the window AC, but many units do not have remote control features. Furthermore, the physical remote is required for initial setup. This proved problematic for some installations where the remote was lost or its battery had expired. Because HEMS installations took place in the fall and winter, it was hardly surprising that the remote was not always handy. The controller needs to be plugged in and mounted in a location with a direct line-of-sight to the window AC or MSHP IR sensor. The Sensibo controller had a fairly short power cord, which often made installation challenging, especially in older homes with few power outlets. These peculiarities notwithstanding, window AC controllers were some of the easier devices to set up. The app was basic but usable. For utility service areas that have many window ACs, we recommend incentivizing window AC controllers in their programs.

Convenience is a key driver and lack of it is a major constraint. Many people are willing to purchase a product and learn how to use it if they believe their lives will be made easier. One participant reported that he programmed his bedroom lights to provide a gradual wake sequence and configured his home office to be powered off for 12 hours each day using the smart plugs. Once the introductory barrier was overcome, many people thoroughly embraced the convenience features.

Conversely, if the learning or commissioning process is perceived to be too cumbersome the audience may be lost forever. One skeptical, would-be participant was somewhat reluctantly going along with the HEMS site visit (that his partner had signed up for), but as soon as one smart bulb failed to connect via Wi-Fi on the first try, he became convinced that these technologies were a waste of his time. This was not the only household that was sensitive to installation time. Across the board small differences in installation time made big differences in perception, and consequently the homeowners for whom the light bulbs connected immediately, the HEMS journey began with a much more positive impression than for those whose bulbs required an initial 5-minute firmware update. The latter situation is difficult to avoid, particularly with these types of new technologies that are constantly pushing updates to improve user experience. It is worth noting that newly purchased products may have a high likelihood of not having the most up-to-date firmware—a result of sitting on the shelf for weeks and months prior to being purchased. For similar site visit situations in the future, it could be helpful to open the boxes in advance of the site visit and take care of any firmware updates.

Voice assistants appear to be here to stay. While not an energy-saving device itself, Alexa (and others like it) can be a powerful hook to get people to embrace smart controls. Although most participants reported initially that they were motivated primarily by smart thermostat, during the HEMS visit it often became clear that the smart speaker was in fact the upgrade that excited people the most.

Installation difficulties were numerous and significant. DIY systems are often not as straightforward as advertised. This was seen across the wide range of products targeting different end uses. Wi-Fi signal in homes is often unreliable, making it difficult to set up and demonstrate new devices, and we found that most homes (even small condominiums) had extenders and/or multiple networks. Even with the extenders, cold spots were everywhere, and some participants have since complained about lights falling off their network, so this is a chronic issue. In addition, we discovered that people do not necessarily know or have easy access to their Wi-Fi passwords, which were required to connect devices to their home Wi-Fi networks.

Smart bulbs save significant energy if replacing non-LED bulbs, but otherwise the savings depend on the details of how people use the remote and schedule features and whether they use the dimming function. Our data showed more overall usage of the smart bulbs relative to the bulbs they replaced, possibly owing to the ability to set up schedules that operated the lights more often than the homeowners would otherwise. Initial feedback from homeowners was that they were excited about the controllability of the smart bulbs so from a consumer engagement standpoint the enthusiasm may be worth the cost and potentially increased usage. Smart bulbs were generally easy to install so they are a good candidate for DIY measures. Making sure that existing rebates for LEDs can be used for smart bulbs, and possibly offering higher rebate for the more expensive smart bulbs will likely increase uptake. Programs may wish to consider packaging smart bulbs with a voice assistant.

Schedules almost always improve convenience but could increase or reduce energy use depending on the implementation. Schedules with setbacks when residents are not home are the main way that smart thermostats and window AC controllers can provide savings, but that is not necessarily how the scheduling function was used. There were cases where the energy use clearly went up after smart controllers were installed. This likely resulted in improved comfort, which is a benefit to consumers even with an energy penalty. It is possible that providing homeowners with an easier way to adjust their thermostat (such as from a smartphone app) led them to find their preferred set point more easily. In the case of lighting, being able to set up a schedule or use the voice assistant to turn on lights may have made the use of some lights more convenient than they were before.

Plug-load controllers should be purchased to address specific use cases and needs and may not be a good fit for a demonstration project that involves hunting around for the right application during the site visit. It was difficult to find plug loads that were suitable to use with plug-load controllers. A few good examples were holiday lights, lamps with non-standard bulbs, and diffuser candles. In most cases if a plug load seemed a good fit the homeowners already had them on a timer switch. On the other hand, there are plug loads where a controller would provide significant savings. This may be an opportunity for further research or improved education to point people toward effective applications, perhaps by sharing a list of examples. Programs could offer rebates (and possibly bundle with a voice assistant) but should try to give guidance so they are useful.

Advanced power strips can be challenging for consumers to adopt if they interfere with the way people normally operate their electronics. The 15 households that participated in this demonstration all experienced some difficulty with the motion-sensing APS. Of all of the HEMS devices employed in this demonstration, the APS was the only product where the feedback was entirely negative. This was in stark contrast to the other devices which, albeit occasional glitches or minor irritations, generally improved convenience for people. It is possible that with more dedicated user training some of the obstacles may be overcome, and the technology is advancing fast to meet the demands of users A simpler solution could be more acceptable to users, such as a collection of controlled outlets that can be scheduled or turned off via a voice assistant.

Smart home features and functionalities are still very new to people and the importance of homeowner interactions cannot be overstated. At first many participants seemed overwhelmed by the confusing array of features and app functions presented to them, on top of the basic functions of the new HEMS devices. In particular, it mattered which household members were present during the installation. For some of the site visits, it was clear that the resident who was home for the installation and orientation was not the same person who had initially volunteered their household for the demonstration. In these cases, it was more challenging to engage the user who was present and explain the various HEMS capabilities in sufficient enough detail to be confident that the knowledge would be shared with all other household members. One participant followed up with us several months after the initial installation to request an additional walk through and introduction to the devices because the household member who was home for the installation could not remember how all the devices worked. The participants in this demonstration largely reported positive experiences with the smart home devices, but to obtain their buy-in required no small amount of user support and continued engagement.

5 References

Canalys, 2018. Smart speakers are the fastest-growing consumer tech; shipments to surpass 50 million in 2018.

URL https://www.canalys.com/newsroom/

smart-speakers-are-fastest-growing-consumer-tech-shipments-surpass-50-million-2018

Earle, L., Sparn, B., 2012. Results of laboratory testing of advanced power strips. In: ACEEE Summer Study Proceedings.

ecobee, 2013. Savings from your ecobee. URL https://www.ecobee.com/savings/

ENERGY STAR, 2017. Energy star smart thermostat: ecobee 4. URL

https://www.energystar.gov/productfinder/product/certified-connected-thermostats/details/2295130

NEEP, 2015. Opportunities for home energy management systems (hems) in advancing residential energy efficiency programs. Tech. rep.

URL https://neep.org/sites/default/files/resources/2015%20HEMS%20Research%20Report.pdf

Nest, 2015. Energy savings from the nest learning thermostat: Energy bill analysis results - white paper. Tech. rep.

URL http://downloads.nest.com/press/documents/energy-savings-white-paper.pdf

NOAA, 2018. Noaa national centers for environmental information: Land-based station data. URL https://www.ncdc.noaa.gov/data-access/land-based-station-data

Olmstead, K., 2017. Nearly half of americans use digital voice assistants, mostly on their smartphones. Pew Research Center.

Robinson, J., Narayanamurthy, R., Clarin, B., Lee, C., Bansal, P., 2016. National study of potential of smart thermostats for energy efficiency and demand response. In: ACEEE Summer Study Proceedings.

Appendix A. Quick Start Guide

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Thank you for participating in this project with the National Renewable Energy Lab!

Several phone apps will give you the full functionality described below.

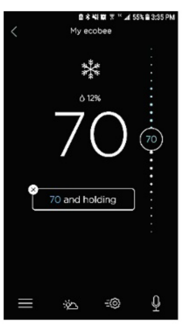
Amazon Alexa	ecobee	Sensibo	Kasa	econnect
Amazon Alexa App	Ecobee (if applicable)	Sensibo (if applicable)	TP-Link Kasa	Embertec Emberconnect

Schedule Your Thermostat or Window Air Conditioner

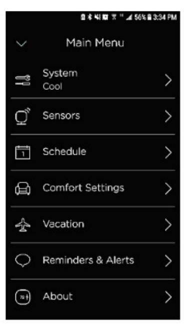
It's easy to adjust your thermostat so that you minimize heating and cooling energy use during periods when nobody is home. By setting a schedule, you'll ensure your home is comfortable when you're there. You can adjust your schedule from your smart phone if your day changes.

Ecobee

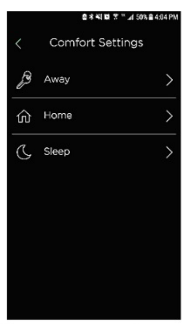
Your Ecobee app allows you to schedule your HVAC system using "comfort settings" that define different situations, such as home or away. Build your schedule by adding comfort settings to the day, editing or creating new comfort settings if you need them.



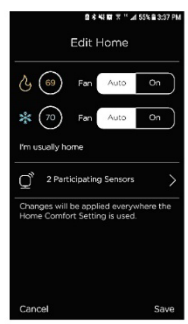
Select the Menu icon in the lower left of home screen (three horizontal lines).



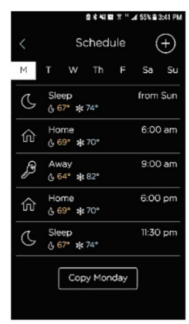
Go to "Comfort Settings".



There are preset comfort settings for common situations – Sleep, Home, and Away. You can create new comfort settings on the app.



Each comfort setting has default setpoints for summer and winter. Change the setpoints to match your preferences.

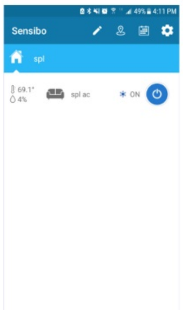


From the Main Menu, select "Schedule" and click "+" to add a comfort setting, start time. Use the Copy button to apply the schedule to other days.

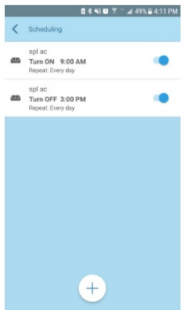
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sensibo

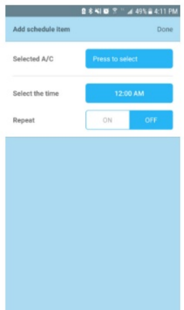
The Sensibo app allows you create a schedule for your window air conditioner (A/C) unit(s), and to set up "locational awareness."



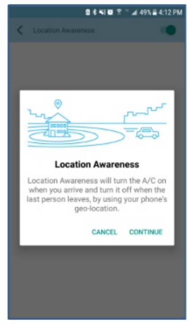
To create a schedule, select the calendar icon at the top of the home screen.



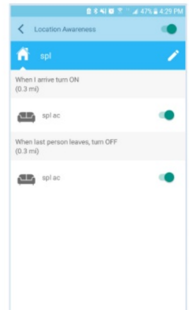
Then, add on and off times.



Select the unit you want to configure. If you are creating an "On" event, you chose the mode, setpoint, and fan state. (Note: The default setpoint is 90°F.) Select the time and if you want this event to repeat on other days.



The Location Awareness feature allows you to control your window A/C unit with geolocation.

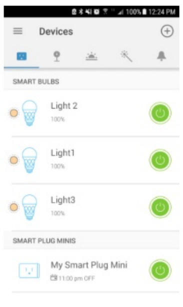


Select the units you want to control with the app and select the radius around your house that you want to use for control.

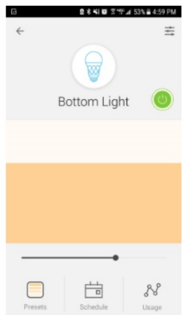
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Schedule Your Lights and Plug Load Controllers

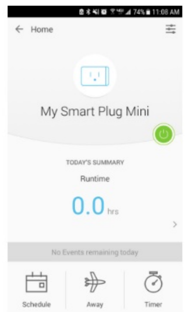
Creating a schedule for lights and plug loads can help ensure that devices are on only when you need them. Use the TP-Link Kasa app to create a schedule for the plug controllers or smart bulbs. The plug controller also can be controlled with a timer or with the "Away" mode. The app allows you to create scenes that can control multiple devices at the same time.



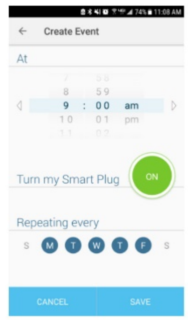
Turn devices on/off from the main screen using the power buttons. Dim bulbs using the yellow dot on the left.

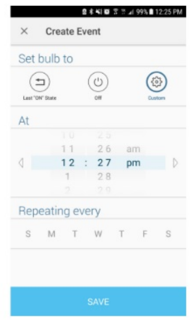


The smart bulbs have a dimming bar, a place to save dimming settings, scheduling, and a usage history.

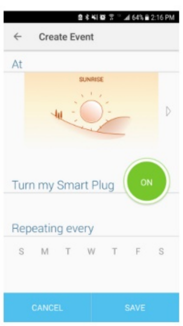


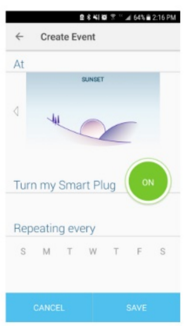
The smart plug has a more control options: scheduling, away mode, and timer.



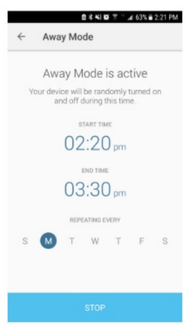


After you select the schedule option, click "+" to create new events. The event page for plugs (left) and bulbs (right) lets you decide when to turn them on and off. Bulbs can also be dimmed in an event.

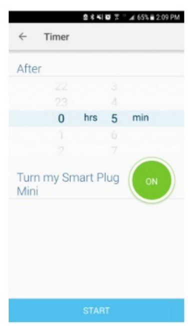




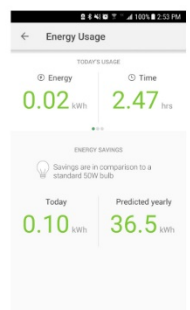
A schedule can also include sunrise or sunset, based on your location. Access the sunrise and sunset options by using the left and right arrows in the event schedule time selector.



"Away Mode" will turn on the plug randomly during the preset period. Start and end times can be sunset or sunrise. (N/A for bulbs)



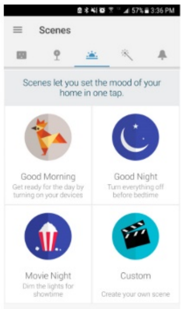
The last option for plug load control is a timer. The device control will be implemented when the timer ends. (N/A for bulbs)



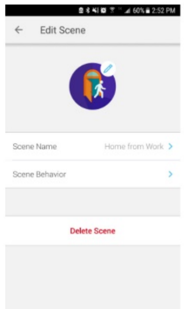
The smart bulbs include an option to view energy usage and run time for each bulb. (N/A for smart plug)

NATIONAL RENEWABLE ENERGY LABORATORY

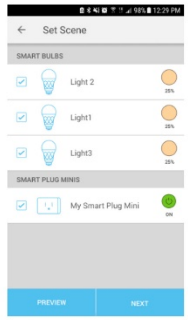
Scenes are another tool for controlling the Kasa devices. You can create groups of settings for all your Kasa-linked devices. Tap the scene you want to use to control multiple devices at once.



From the home screen, select the Scene icon from the menu bar. Start with some suggested scenes or create your own custom scenes.



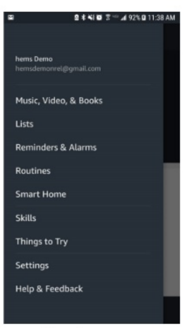
Choose a custom icon and name. Then select "Scene Behavior" to program your devices.



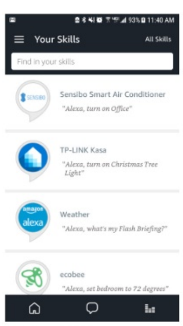
Select the devices you want to use and what should happen when this scene is in use.

Configure Alexa for Voice Control

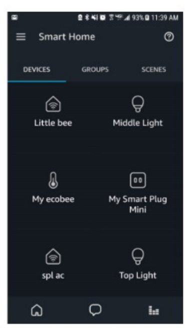
The Alexa app is not needed on a regular basis. However, there are a few things to set up in the app before you can control your devices by voice.



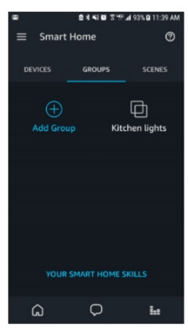
From the home screen, select the menu button (upper left). Access the Skill page to connect new devices to Alexa.



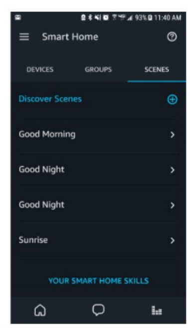
On the Skills page, find a new skill from the search bar or view your existing skills.



From the main menu, select "Smart Home" to see the connected devices. It also provides simple control of the devices.



The Groups window allows you to group items (e.g., light bulbs) together for control.

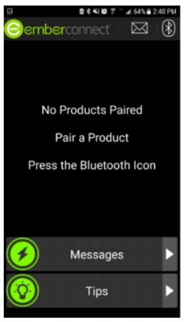


Scenes are imported from other apps (e.g., Kasa) so you can use features created elsewhere.

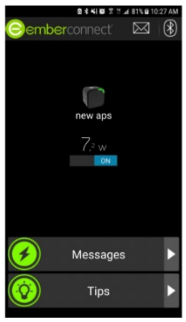
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Monitoring with the Embertec Advanced Power Strip

Your Embertec power strip can send power usage data (for the controlled outlets only) to your phone via Bluetooth using the Embertec emberconnect app.



Select the Bluetooth icon (upper right) to pair your power strip; pairing code is 000000 (6 zeros).



Once paired, the app will show the current power draw from the controlled outlets.

Click on the sensor icon for more options. You can turn off outlets, adjust the timer period, or change LED brightness.

If you need assistance with your devices and cannot find an answer here or in the device manual, please contact NREL:
bethany.sparn@nrel.gov or lieko.earle@nrel.gov
303-384-7442 303-275-4355

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State Energy Research and Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

NEW YORK
STATE OF
OPPORTUNITY.
NYSERDA

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | Alicia Barton, President and CEO