Home Energy Management Systems (HEMS) Paths to Savings: On-Ramps and Dead Ends

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ABSTRACT

Automation with home energy management systems (HEMS) products, an increasingly popular strategy, can provide energy and peak demand savings; improve the speed and rigor of evaluation, measurement, and verification (EM&V); and promote customer engagement. With HEMS, residents can access dashboard displays, often via computers and mobile devices, to manage the energy use of their homes.

In a recent multistate study in the Northeast, we researched energy switches for a variety of end uses integrated within HEMS by assessing end-use and equipment-specific loads, the potential for savings, and the customer experience. A sample of customers received programmable energy switches on equipment such as HVAC, electronics, appliances, and pool pumps. For each switch, a stream of 15-minute interval data was generated, which provided specific load data and allowed us to assess applications with the greatest potential for energy and demand savings. Half of the sample customers received additional coaching to set control schedules, giving us insight into the optimal level of intervention. We also assessed the customer's experience with HEMS products in terms of ease of use, functionality, satisfaction, and level of activity.

In this paper, we will discuss results applicable for program managers who are considering HEMS programs—such as the optimal delivery channel, aspects of key importance from the customer's perspective, areas for greatest savings potential, and cost-effectiveness—and the need to present a business case for this burgeoning technology.

HEMS Overview

Home automation with home energy management systems (HEMS) products is a growing energy management strategy that can provide energy and peak demand savings and increase the speed and rigor of evaluation, measurement, and verification (EM&V), while increasing customer engagement and providing them with enhanced energy management services. HEMS can be broadly defined as systems that enable households to manage their energy consumption (including hardware and software linked via a network). HEMS can take multiple forms (Karlin et al. 2015):

- HEMS can provide consumers with information about how they use energy in the home and/or offer prompts to modify consumption.
- HEMS can provide the household or third parties (e.g., utilities) with the ability to control energy-consuming processes in the home, remotely via a smartphone or web service or through in-home displays. These devices can be either manually controlled or programmed using a set of rules that can be scheduled or optimized based on user behavior.

Home automation as an energy management strategy is becoming increasingly popular as a variety of HEMS enter the market. A 2015 HEMS market characterization study identified 244 HEMS products available, ranging from smart controls for lighting, HVAC, and appliances to load monitoring and energy analytics software that can be integrated with renewables and energy storage (Karlin et al. 2015).

HEMS offer new opportunities for controlling home devices to save energy and reduce peak loads. For example, smart thermostats use occupancy sensors or geolocation services with background algorithms to learn user behavior and automatically control heating and cooling. In this way, HEMS can automatically reduce heating and cooling when the home is unoccupied and take advantage of savings without compromising comfort. In addition, HEMS provide a platform for utilities to administer direct load control, behavioral demand response, and pricing programs that can reduce peak demand.

A wide range of HEMS products have recently entered the market that offer several types of technologies to promote energy and demand savings. A 2015 review of recent HEMS programs shows energy savings from HEMS products range from 2% to 22% and demand savings range from 0.5 to 1.0 kW per customer. Figure 1 shows savings by HEMS product type and fuel type.

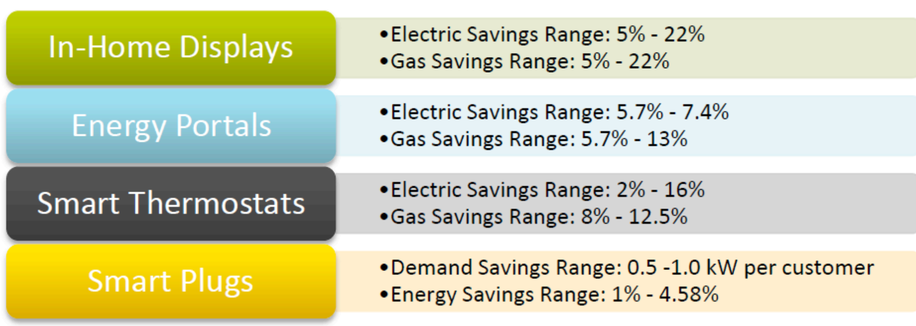

Figure 1. Energy savings from home automation by HEMS product type and fuel.
Source: NEEP 2015.

HEMS products offer opportunities to identify homes that consume a high amount of energy attributable to underperforming equipment or user behavior. For instance, utilities can use the performance data collected on smart thermostats to diagnose poorly performing HVAC systems or leaky homes. By identifying opportunities for energy efficiency improvements, HEMS products can help program administrators target energy efficiency program offerings to the appropriate customers.

A 2015 report on HEMS notes that randomized control trials are considered the best practice for EM&V of behavior-based programs, but this method has limitations for some program designs that HEMS can overcome (CLEAResult, 2015). Many HEMS products provide an alternative EM&V method by collecting interval data, even in the absence of advanced metering infrastructure. These interval data can be used as an EM&V tool to evaluate savings from installed measures with greater accuracy and to evaluate demand savings delivered through demand response programs (e.g., direct load control, dynamic pricing). In addition to energy data, some HEMS provide other appliance performance metrics, such as system run-time or home temperature. With intervals (often at the one-minute level) being collected on a real-time basis, program EM&V can benefit in terms of accuracy, speed, and rigor. Analysis of these data can also help identify and fix program issues mid-cycle, such as problems with contractors or underperforming measures.

Home automation can also help engage customers while providing them with an energy management service they are already looking for. Results from a 2014 home automation market survey using data collected nationwide indicated that consumers were already interested in opportunities to save energy through home automation (CLEAResult, 2015). The study found that "automated energy savings" was the number one reason survey respondents were considering home automation. By engaging customers with an energy management technology they are already interested in, program administrators can initiate a reengagement cycle to improve programs and maintain customer participation, as shown in Figure 2.

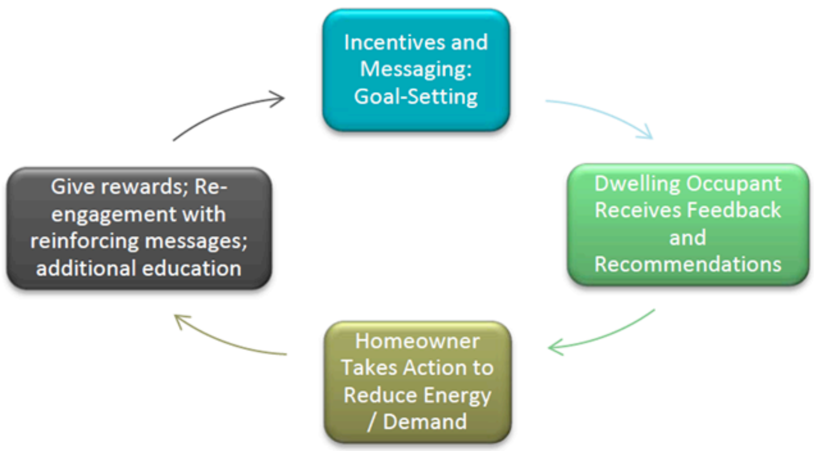

Figure 2. Customer engagement and reengagement cycle. *Source*: NEEP 2015.

As more customers adopt HEMS products, program administrators can leverage the platform (e.g., Nest or Building 36) to create integrated programs to advance their energy efficiency and demand management goals, while engaging customers and enhancing their experience.

Study Overview

In early 2016, Cadmus completed a technical demonstration project for Eversource focused on assessing HEMS and energy switches used to control equipment-specific usage. Specifically, we investigated the energy impacts of installing programmable energy switches on a sample of homes, some with existing thermostat-based HEMS, and we identified appliances with the greatest potential for savings. The switches communicate wirelessly to a web-based dashboard, report 15-minute interval energy-use data, and respond to automation controls set on the dashboard. By measuring usage levels before and after installation of automation controls, Cadmus developed load shapes for several end uses and estimated the potential for savings by equipment and end-use level. Assessment of the savings potential from energy switches is the primary objective of this research; additional objectives were assessment of aspects of the user experience and barriers to using control devices on specific measures.

Participant Sample

Cadmus installed an average of four 110-volt energy switches on various plug load devices in 41 Massachusetts homes and 20 Connecticut homes. We worked with an electrician to install additional energy switch devices on higher voltage and direct-wired end uses: one 220-volt domestic hot water tank, three pool pumps, and two wall lights.

All homeowners received a three-page instruction manual on how to program their energy switches. After the switches were installed for a month, we performed outreach to 30 homeowners to encourage them to program recommended automated-control schedules, and we directly programmed devices in 13 homes with the homeowners' permission. In all, 29 homeowners had devices programmed, 13 by Cadmus and 16 by the homeowner. Figure 3 shows the number of participants who received each type of treatment and the total number of participants from each group who programmed automation controls.[1]

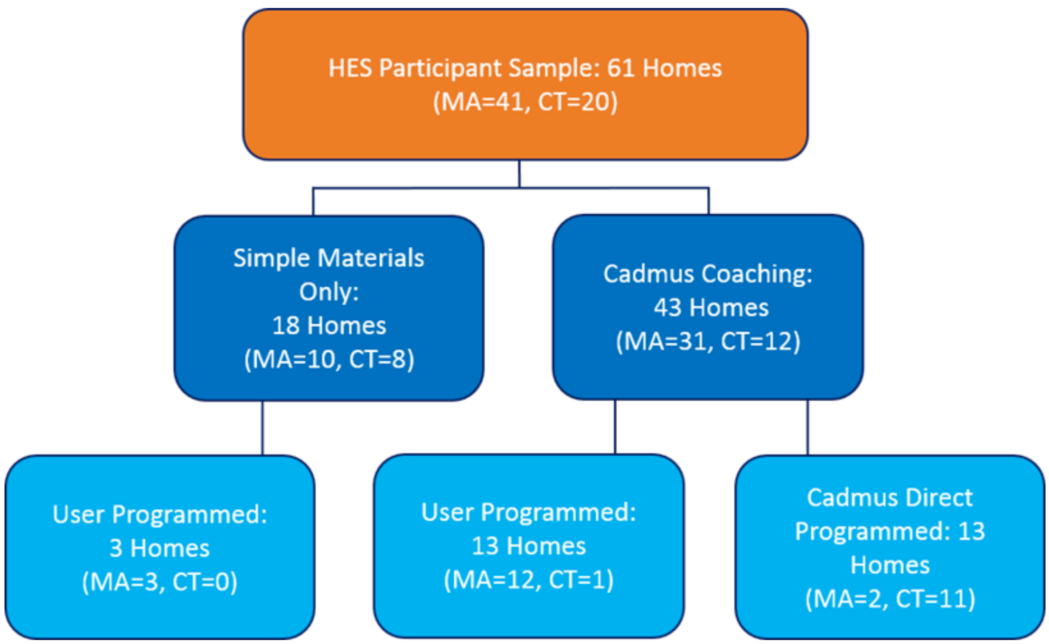

Figure 3. Participant sample and treatment plan. *Source*: Cadmus 2016

Cadmus randomly selected sites for recruitment to reach the targets of 41 Massachusetts and 20 Connecticut sites. The Massachusetts sample came from a population of Home Energy Savings (HES) program participants who received a smart programmable thermostat with Building 36 hardware and a web-based dashboard. The Connecticut sample came from a population of HES participants who did not previously have a Building 36 gateway or access to the web-based dashboard.

[1] Because of an insufficient number of sites where homeowners independently programmed controls, this report does not explore differences between direct vs. user programming (e.g., differences in control sequences).

Participant Recruitment

Cadmus recruited customers from the HES participant populations, soliciting those interested in participating in the HEMS technical demonstration. These participants then received free programmable energy switches and two years of free access to the web-based dashboard (which retails for approximately $18 per month).

Installed Equipment

Massachusetts sites already had a z-wave programmable thermostat and a gateway device as part of Building 36 participation (hardwired into the home modem). Cadmus installed z-wave gateway devices at the Connecticut sites (also hardwired into home modems). The gateway device communicates directly with the secure Building 36 server, which supports a dashboard that displays energy consumption and allows users to schedule clock-based control schemes. Images of several of the technologies used in this study are shown in Figure 4. Table 1 lists quantities of equipment types and quantities of controlled units.

Figure 4. Technologies used (clockwise from top left: 220-volt z-wave energy switch, lighting wall switch, z-wave gateway device, and 110-volt z-wave energy switch). *Source*: Cadmus 2016

Table 1 Count of installed energy switches by equipment and end use*

Switch type	Equipment and end use	Quantity installed	Count of controlled devices
110-volt	Entertainment (e.g., TV and DVD bundle)	105	34
	Room air conditioner	57	10
	Dehumidifier**	34	12
	Home office (e.g., printers, monitors)	47	17
	Lamp	8	3
	Room fan	5	2
	Coffeemaker (e.g., K-Cup)	11	5
	Other (e.g., exercise equipment)	13	4
220-volt	Pool pump	3	3
	Domestic hot water	1	1
Wall light switch	Lighting (i.e., outdoor)	2	2

* On average, participants received four to five 110-volt switches per household.

** Of the total dehumidifiers, nine were identified as heavy-use units.

Control Settings

After a month of monitoring usage, Cadmus reviewed sites' dashboards to identify patterns of use and potential recommendations for control schedules. We identified automation schedules for 43 of the 60 homes and offered participants coaching to encourage the creation of programmed control schemes. The intent of this design was to compare a group of homes that received recommended automation schedules including the interface to homes that did not receive this intervention. Additionally, we programmed devices at 13 sites after receiving permission from homeowners.

Savings Analysis

In order to maximize the available sample, we used data from all of the participants (with or without controls) for a given equipment type to characterize the pre-control load (i.e., typical wattage and consumption). Only the subsample of homes with controlled devices contributed to estimates of the post-control period (i.e., reduced hours of use).

For electronic devices, savings accrue from eliminating standby energy for a period of time through clock controls. Controlled entertainment centers were televisions and other devices including DVD and VCR players, but not cable set-top boxes. We identified the average hours per day that the appliance was programmed to be off. Savings were the average standby energy for that end use multiplied by the average daily hours that the end use was programmed to be off.

For dehumidifiers, we found the load shape of the active energy use for the population prior to applying controls. For houses that programmed controls with dehumidifiers, we determined the average daily hours that the dehumidifier was programmed to be off. We multiplied the average active load by the number of hours off, annualized to six months, to calculate the savings. We then found a subset of dehumidifiers that ran continuously, and we repeated the analysis for the heavy-use units.

For room air conditioners, we inspected an hourly pre- and post-control load shape for each unit that was controlled. We found the units to be heavily controlled by time of day prior to the use of the control clock. We were unable to find any savings for this measure.

For pool pumps, we measured the power draw of the pump with a voltmeter. We made note of the hours of use from the baseline condition (i.e., electromechanical clock). We then found the smart clock schedule set by the homeowner. We calculated the savings by determining the difference between the daily hours of use multiplied by the power annualized to four months of pool use.

For water heaters, we determined the average daily pre-control energy use and the average daily post-control energy use.

Study Findings

Summary Savings Potential by Equipment Type

By analyzing each metered technology type's hourly and daily energy use before control settings, we calculated the potential for savings based on annual energy usage, standby power, and active power for a range of equipment types, as shown in Table 2.

Table 2 Annual energy usage by equipment type*

End use	Technology	Average standby power (W)**	Average active power (W)**	Annual energy use (kWh)
Appliances and electronics	Dehumidifiers (all)***	n/a	142	623
	Dehumidifiers (heavy-use units)***	n/a	349	1,531
	K-Cup coffeemaker	5	19	73
	Refrigerator and freezer	n/a	79	695
	TV and entertainment	7	25	218
HVAC	Room air conditioner	n/a	81	236
Water heating	Domestic hot water	n/a	145	1,271
Other	Pool pump	n/a	1,097	1,619

* Annual energy usage based on full population of sites with given technologies, including those without controls.

** Standby and active power are based on average participant usage and do not reflect maximum power draw.

*** Dehumidifiers ranged in usage, with the top 30% of units (i.e., heavy-use units) averaging 1,531 kWh annually.

Annual energy use is one determining factor of savings potential. Dehumidifiers and pool pumps use significantly more annual energy than coffeemakers and TVs. Several appliances show greater potential for savings based on the ability to control active versus standby power. For example, standby wattage for TVs and DVD bundles is seven watts, indicating a lower potential for annual savings associated with this sort of control scheme. By comparison, dehumidifier active power shows much more potential for savings through controls. Essentially, there could be more savings potential in terms of controlling active power for select equipment compared to the controlled shut-off of standby power. Table 3 provides the energy and demand savings by equipment type, along with simple payback.

Table 3 Annual energy and demand savings by equipment type

End use	Technology	Costs	Avg. daily hours controlled off	Annual energy savings (kWh)	Demand savings (kW)*	Number of controlled switches	Simple payback (years)**
Appliances and electronics	Dehumidifiers (all)	$50	2.1	54	0.142	12	4.6
	Dehumidifiers (heavy-use units)	$50	2.1	134	0.349	12	1.9
	K-Cup coffeemaker	$50	11.7	21	n/a	5	11.7
	TV and entertainment	$50	7	18	n/a	34	14
HVAC	Room AC	$50	11.6	n/a***	0.110	10	n/a
Water heating	Domestic hot water	$795	3	0	4.5****	1	n/a
Other	Pool pump	$795	14.3	403	1.1****	3	9.9
Other	Pool pump	$795	18.3	761	1.1****	3	5.2

* Demand savings is the load shape average kW, which is the hourly average kWh.

** Payback calculation assumes an energy rate of $0.20/kWh. U.S. Bureau of Labor Statistics.

*** During the study period, room ACs were already being used opportunistically by homeowners prior to clock controls (i.e., toward the end of the cooling season).

**** 4.5 kW domestic hot water (DHW) is the nameplate load of the 80 gallon electric unit (i.e., GE model GE80T06AAG). 1.1 kW pool pump is the average spot measurement of power load.

Measure-Specific Findings: Dehumidifiers

Dehumidifiers were one of the measures that demonstrated the greatest potential for energy and demand savings. Dehumidifiers tend to operate continuously when emptied regularly or continuously piped. Energy use per day ranges from 2.0 to 8.4 kWh, or up to four times the energy use of an average refrigerator. Shutting dehumidifiers off for short periods (e.g., two hours per day) can save energy and deliver demand savings without large changes to the humidity in the space they serve.

A distinction between the types of dehumidifiers relates to whether the unit is plumbed or non-plumbed for condensate water flow; plumbed units only turn off when they reach a humidity setpoint. Non-plumbed units turn off once the reservoir is full, requiring manual removal of the water before the equipment can continue operating. There is greater potential for savings and lower risk in controlling a plumbed dehumidifier. If a non-plumbed unit is not emptied, then the basement humidity will increase. This can occur for half a day up to a few days, until the homeowner remembers to empty the reservoir. When the homeowner empties the unit and it restarts, the dehumidifier has to make up for time lost; interrupting the unit's operation would slow down its progress to achieve its steady-state humidity setpoint. However, a plumbed unit can be controlled because its operation is solely dependent on a setpoint, rather than human intervention.

Dehumidifiers have a high average peak wattage that facilitates demand savings and energy savings. We found that the average energy use of dehumidifiers was nearly twice that of the average refrigerator (approximately 142 watts vs. 79 watts). When we looked at a subset of the most heavily used dehumidifiers, the average hour of use for heavy-use dehumidifiers was over four times that of an average refrigerator. Figure 5 shows the load shape for the average dehumidifier.

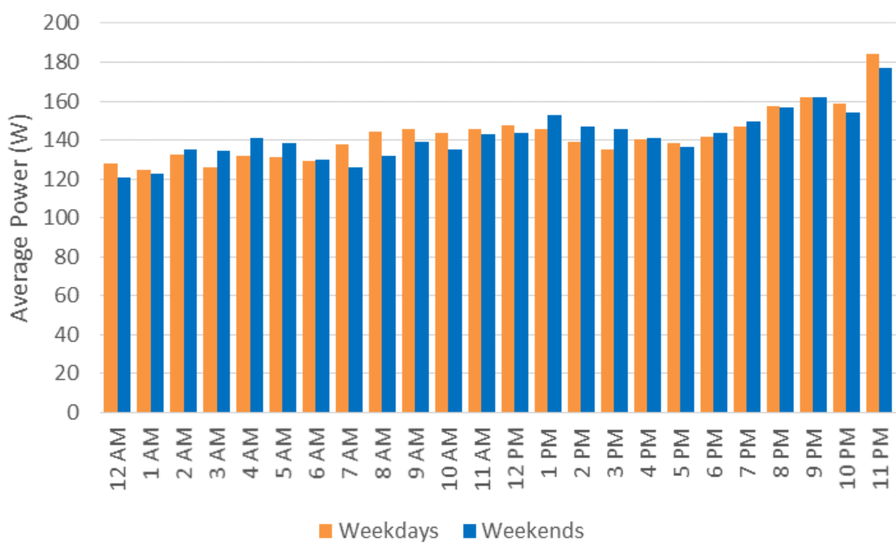

Figure 5. Average dehumidifier load shape (pre-controls). *Source*: Cadmus 2016.

Figure 6 shows the load shape for one of the most heavily used dehumidifiers in our sample, which ran most of each day. This load shape demonstrates that approximately 0.6 kW were completely reduced through automation controls, rather than any of the energy consumption being shifted to the post-control period.

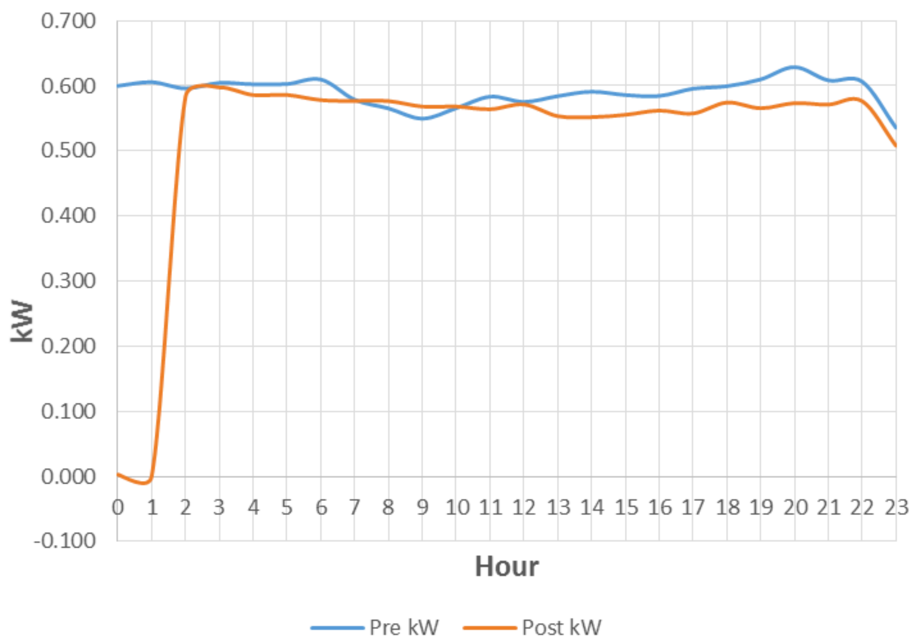

Figure 6.Site-specific dehumidifier load shape example (pre- and post-controls clock control, midnight to 0200 hours, off daily). *Source*: Cadmus 2016.

The average demand for all dehumidifiers was 142 watts. The average demand for heavy-use dehumidifiers (units used almost continuously) was 349 watts. A program could target sites with dehumidifiers that are plumbed to a drain because they are likely to run almost continuously. Heavy-use dehumidifiers can be targeted for demand savings and energy savings. We found that turning off heavier use dehumidifiers for two hours nightly did not appreciably increase the relative humidity of the space. Figure 7 shows the average load shape of heavy-use dehumidifiers.

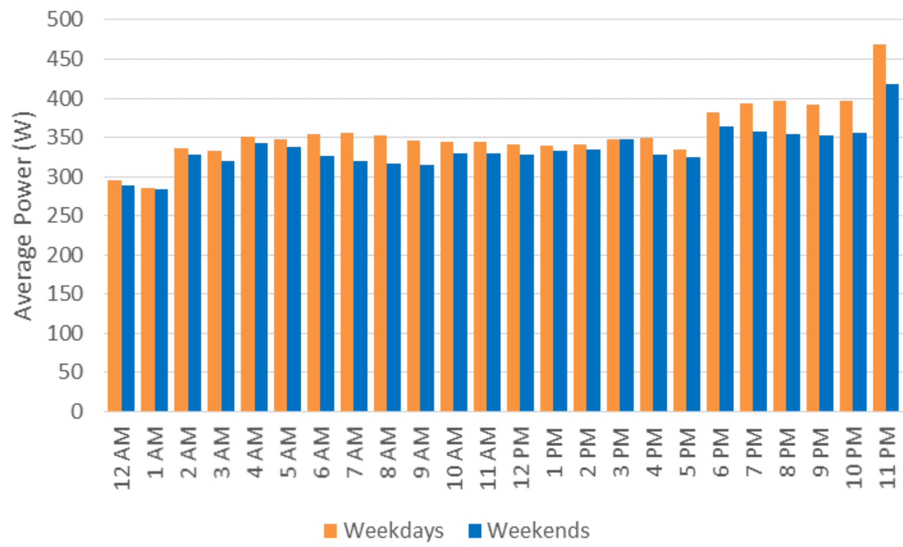

Figure 7. Average heavy-use dehumidifier load shape (pre-controls), n = 9.
Source: Cadmus 2016.

By combining an energy switch with a wireless temperature humidity sensor, a program could ensure that a clock-based automation shutoff of a dehumidifier would not occur if the space's relative humidity was greater than a set threshold. The HEMS we studied did not have this capability.

Research Applicability

From an implementation perspective, this technical demonstration study revealed several important lessons regarding program delivery implications, the price customers are willing to pay, customer engagement, and the necessity for an anchor product, as we describe in the following sections.

Program Delivery Method

The program administrator was interested in finding out whether energy switches could be a viable upstream offering at big box stores or whether direct installation was a better delivery method. A significant finding from the study was that programs promoting energy switches should have qualified technicians perform direct installation and programming because homeowners do not program the devices on their own.

To answer the delivery method question, half of the participants (30) received coaching or their smart energy switches were programmed for them, and the other half of participants received no coaching. All 60 participants received a four-page instruction manual as a PDF that included dashboard screenshots to help walk them through the interface. The coached participants received specific on/off schedule recommendations via email. Of the 30 customers who did not receive coaching, only one completed programming. Several participants logged in but did not schedule the smart switches. The program administrator gave the switches to customers at no cost as part of the technical demonstration, which likely lowered these customers' motivation. Nonetheless, this finding suggests that a technician should directly install and program the units at the time of the audit.

Price Sensitivity

The technology was offered at no cost, but the program administrator was interested in understanding what customers would be willing to pay. For this study, we conducted a participant survey that included questions about price sensitivity. The survey questions asked respondents about the price of the switch and the cost of monthly access to the dashboard. For both items, participants were asked the following questions: at what price point is the cost so low that they question the quality, and what do they consider a bargain, expensive, and too expensive?

The survey results showed that for the energy switch, participants consider $15 a deal and $32 expensive, so the appropriate price point would probably be somewhere in that range. The current retail price for these switches is about $45. Survey results suggest that monthly access fees to the dashboard should cost between $2 and $5 per month; however, vendors could offer variable pricing based on interface functionality. These survey results suggest that for this technology to be rolled out on a broader scale, the program administrator would need to work with the manufacturer to lower the cost, which might be accomplished through bulk procurement and more competition in the market.

Customer Engagement

Tracking multiple products through a single platform would garner the most engagement from customers. For example, these smart energy switches are part of the Building 36 suite of services, which includes smart thermostats, image sensors, controls for locks and garage doors, video monitoring, lighting controls, and water management. If a customer has other products like a thermostat that they regularly monitor and control through a mobile application, then that would most likely increase their use of other products. The study found that a larger proportion of participants with programmed devices used the system more on average per month, which is intuitive given an increased level of engagement.

The controls and scheduling capabilities need to be user-friendly to increase the likelihood that people will use them. Two drawbacks of this particular product are that users cannot set schedules from a mobile application and they cannot see the current status of the equipment (i.e., on vs. off). Most of the respondents (15 of 18) stated that they use mobile devices, and respondents using mobile devices access the dashboard more often than respondents using computers to access the dashboard.

Anchor Product

Another lesson learned from this study is that most of the applications we metered showed minimal savings with two exceptions: (1) dehumidifiers with an average savings of 54 kWh annually and 134 kWh for heavy use, and (2) pool pumps with metered savings of 403 kWh annually and potential savings of 761 kWh annually. Therefore, customers with dehumidifiers or pool pumps not currently on a timer would be the best populations for programs to focus on.

Without the anchor products of dehumidifiers or pool pumps, the benefits would not outweigh the costs.

Recommendations

To maximize savings, HEMS-based programs should be designed to target the control of appliances' active-use power, rather than the control of standby-use power.

Dehumidifiers are installed as either plumbed or non-plumbed. Homeowners need to empty non-plumbed units regularly to avoid automatic shutoff, whereas homeowners use plumbed units more predictably and consistently. HEMS programs should select or prequalify plumbed units to achieve more predictable results.

Site-specific assessments of pool-pump applications need to assess indoor versus outdoor installation. Outdoor installations need to be in a weathertight enclosure. Although the design specification indicates a 300-foot range for wireless operation between the outdoor switch to the home, we identified errors in control transmissions occurring for one site at 200-foot operation.

Programs promoting energy switches should employ qualified technicians to perform direct installation and programming because we found that homeowners do not program the devices on their own.

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