Smart Thermostats and the Triple Bottom Line: People, Planet, and Profits

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ABSTRACT

It is no secret in the world of energy utilities: Faced with the challenges of declining demand, increased adoption of renewables, and a changing regulatory environment, energy providers are looking for solutions. Changing technology and the ever-expanding availability of big data offer opportunities, but successfully exploiting these opportunities presents a challenge in itself. With their WiFi connectivity and automatic control of heating and cooling systems, smart thermostats are gaining attention for their ability to help meet three key goals: managing customer relationships, meeting aggressive energy-savings targets, and managing demand to avoid peak charges from regional grids.

Drawing on results from two smart thermostat pilot evaluations conducted by Cadmus, this paper presents key findings on opportunities for utilities to engage with customers, increase energy savings, and implement demand response. The paper begins with the results of the largest U.S. third-party evaluation of the Nest thermostat to date, which comprised two related studies in Indiana. These studies compared the gas heating and electric cooling usage of homes with a Nest thermostat to that of homes with conventional manual and programmable thermostats.

Next, the paper presents the evaluation results from a smart thermostat pilot in the Northeast. In this study, the evaluation team tested the use of smart thermostats in combination with HVAC optimization controls, home energy monitoring using AMI data, and a demand response program. The paper also presents the evaluation findings from an assessment of the impacts of various styles of demand response events including smart pre-cooling.

The paper ends with a discussion of the future of smart thermostat programs and how utilities can leverage smart thermostat interval data for modeling and tracking energy savings from various customer actions such as setpoint schedule changes and equipment upgrades.

Introduction

As utilities strive to manage their relationships with customers, meet aggressive energy-savings targets, and manage their demand to avoid peak charges from regional grids, many are searching for new, innovative program offerings. Smart thermostats, which can serve as a tool for automatic HVAC controls and demand response platforms, offer solutions for all three of these goals.

Why Smart Thermostats?

Programmable thermostats, which give users the ability to program a schedule of set temperatures, have the potential to reduce energy use from the levels of conventional, manual thermostats. However, for several reasons, many studies show these thermostats often fail to live up to their promise. A new generation of WiFi-enabled, smart thermostats designed with more user-friendly programming is thought to help eliminate the challenges presented by programmable thermostats. Smart thermostats have schedule-learning features designed to help eliminate the challenges presented by programmable thermostats by shifting the burden of programming from the user to the thermostat. Each of the major thermostat manufacturers has released smart thermostats that can identify opportunities for savings using occupancy sensing, geofencing (triggering of a thermostat setting when a mobile phone enters or exits a boundary around the home), or remote temperature sensing—while also maximizing comfort. This paper shares empirical results demonstrating how smart thermostats can provide increased energy efficiency and comfort. Results also show that when paired with demand response initiatives, smart thermostats can reduce peak demand.

Nest Thermostat Evaluation

From 2013 to 2014, two of Cadmus' utility partners in Indiana, Northern Indiana Public Service Company (NIPSCO) and Vectren, each administered a smart thermostat pilot in their territories. Although several major thermostat manufacturers today, including Honeywell and Ecobee, offer schedule-learning features, the utilities chose the Nest as a representative smart thermostat because it was the only thermostat with built-in occupancy sensing and schedule-learning algorithms at the time. They administered their pilots to a combined total of 1,400 gas and electric customers, making this study the largest of its kind.

Cadmus evaluated the energy savings impact of the Nest in the heating and cooling seasons for customers who have gas furnaces and air conditioning. The evaluation team conducted a billing analysis of participants' energy consumption both before and after the new thermostats were installed and compared the energy savings with that of the programmable thermostats. The team used a control group of over 4,000 NIPSCO and Vectren customer households still using manual thermostats to determine adjusted gross savings from the Nest and programmable thermostats.

Cadmus' evaluation team also installed data loggers in 700 participating homes to track indoor air temperature and air conditioner runtime—the largest installation of this scale to date. In addition, the team conducted a tablet-based pre-installation survey to collect demographic information and a post-installation survey to assess participant behavior and determine any changes over the study period that might eliminate the participant from the analysis. This study found significant savings for the customers who had smart thermostats installed.

Evaluation Findings

NIPSCO

- Participants with the Nest thermostat reduced their heating gas consumption by approximately 13.4%, compared to only 7.8% for participants with a programmable thermostat.
- Nest thermostat users had, on average, a 16.1% reduction in electricity use for cooling.

Vectren

- Participants with the Nest thermostat reduced their heating gas consumption by approximately 12.5%, compared to only 5.0% for participants with a programmable thermostat.
- Nest thermostat users had, on average, a 13.9% reduction in electricity use for cooling.

For the two utilities combined, Cadmus found that, on average, Nest thermostats cut gas used for heating by 13.3% and electricity used for cooling by 14.5%.

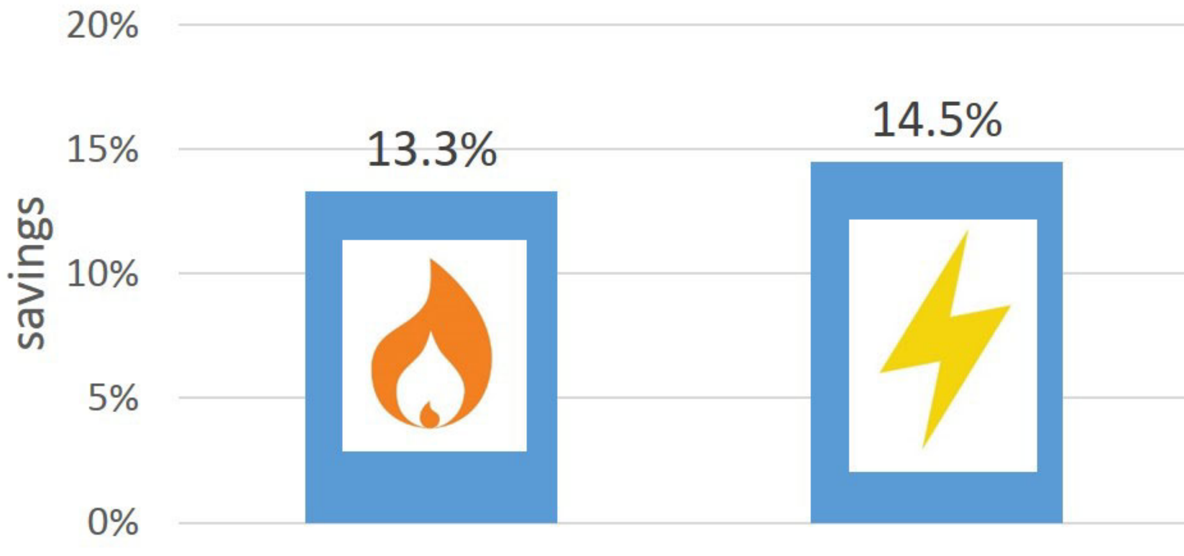

Figure 1. Gas and Electric Savings from Nest Thermostats in Indiana

WeatherBug Home Evaluation

Cadmus' Weatherbug Home evaluation shows that in addition to providing energy efficiency benefits, smart thermostats can be an effective tool for reducing peak demand without adversely affecting comfort.

In 2013 and 2014, National Grid conducted a pilot study in partnership with smart-thermostat pioneer Ecobee and with Earth Networks, the company behind the Weatherbug Home connected-home optimization platform. One key goal of the study was to evaluate the impact of Weatherbug Home's HVAC optimization control software. This software uses real-time, hyper-local weather data from WeatherBug weather stations, historical HVAC runtime data from the Ecobee Smart Si thermostat, and historical energy usage data from the integrated energy meter to optimize HVAC runtimes. The software attempts to save energy while maintaining comfort.

A second key goal of the study was to evaluate the impact of four demand-response events on residential customers' natural gas and electric usage.

National Grid assigned a different treatment to each of two groups. One group of 52 participants received treatment 1: an Ecobee Smart Si Thermostat with integrated energy meter, which provided home energy monitoring capabilities. The second group of 51 participants received the same thermostat with integrated energy meter, but the Ecobee thermostat also connected to WeatherBug Home's HVAC optimization controls. Additionally, participants in this group were invited to participate in four demand-response events.

As a part of the evaluation, Cadmus conducted the following activities:

- Determined the energy (natural gas and electric) impacts of the Ecobee thermostat with and without WeatherBug Home's HVAC optimization controls.

- Verified the demand impacts of and participant experiences with each of the four DR events.

Evaluation Findings

Heating Season Energy Savings

Cadmus found roughly equal energy savings in heating season for groups with and without the HVAC optimization controls. Heating systems with WiFi thermostats and HVAC optimization controls saved about the same in natural gas as heating systems with WiFi thermostats but no HVAC optimization controls.

The group without HVAC optimization controls performed slightly better when considering savings as a percentage of total gas usage: The group without controls saved an average of 9.5%, compared to 9.1% for participants in the group with controls.

The group with controls performed slightly better when considering savings as a percentage of the disaggregated heating load and savings per square foot: The group with controls saved an average of 13.1% of heating gas usage, compared to 12.4% for participants in the group without controls. In terms of heated space, the group with controls saved 0.0480 therms per square foot compared to 0.0460 therms for the group without controls.

Cooling Season Energy Savings

Cooling systems with HVAC optimization controls saved significantly more electricity than cooling systems without HVAC optimization controls. When comparing the groups with and without controls for participants with just one thermostat (savings with multiple thermostats decreased dramatically for both groups), Cadmus found that the group with controls outperformed the group without controls by three times when considering the disaggregated cooling load and five times when considering savings per square foot. Key study findings include the following:

- As a percentage of the disaggregated cooling load, the group with controls saved 16.5%, compared to 5.1% for the group without controls.
- In terms of cooled space, the group with controls saved 0.1808 kWh per square foot, compared with 0.0358 kWh for the group without controls.

Heating Season Comfort

As part of its evaluation, Cadmus designed surveys for both participant groups to collect a variety of information. All participants received an e-mail invitation to the online survey. The surveys achieved a response rate of 46% overall: 23 participants (44%) from the group without HVAC optimization controls completed the survey, and 24 participants (47%) completed the survey from the group with HVAC controls. The surveys were conducted during December 2014.

Participants reported the average temperature settings of 67.7°F during the heating season, with a minimum value of 58°F and a maximum value of 78°F. Table 1 shows winter season comfort ratings during program participation compared to the season before participation.

Table 1. Heating Season Comfort Ratings

Answer	Participants Without Controls		Participants With Controls	
	Responses	%	Responses	%
Did not notice a change in comfort level	13	57%	15	65%
The house is cooler but the comfort level is acceptable	6	26%	5	22%
The house is considerably less comfortable	1	4%	2	9%
Other	3	13%	1	4%

The majority of participants in both groups (57% of those without controls and 65% of those with controls) did not notice changes in comfort levels, while 26% of those without controls and 22% of those with controls found their homes cooler but acceptably comfortable. Only one participant without controls (4%) and two participants with controls (9%) found their homes considerably less comfortable. These findings are similar those of summer cooling comfort levels, with most participants reporting they were acceptably comfortable during the program.

Cooling Season Comfort

Customers reported maintaining average home temperatures of 72.3°F during the summer cooling season, with a minimum value of 65 degrees and a maximum of 81°F. Cadmus asked participants to rate their comfort levels during the cooling season. Table 2 shows results for the group with a WiFi thermostat but no HVAC optimization controls.

Table 2. Summer Cooling Season Comfort Ratings

Answer	Responses	%
Did not notice a change in comfort level	14	61%
The house is warmer but the comfort level is acceptable	6	26%
The house is considerably less comfortable	2	9%
Other: "House was more comfortable"	1	4%
Total	23	100%

The majority of participants (61%) did not notice changes in comfort levels compared to the season before participation. One respondent found levels more comfortable. Approximately one-quarter (26%) found their house warmer but acceptably comfortable. Only two respondents found their house considerably less comfortable. Overall, the program’s curtailment settings were acceptable to 91% of participants.

Peak Demand Impacts

In addition to saving energy and optimizing comfort, smart thermostats provide a platform for utilities to administer direct load control and behavioral demand response programs that can reduce peak demand. This increases their potential to provide better comfort and greater savings during demand response events. Because smart thermostats collect historical HVAC runtime and time-to-temperature data, they have the potential to optimize the length of pre-cooling events, which provide cooling prior to the peak-demand period to improve comfort during the demand response event. Optimization of these events involves providing enough pre-cooling to ensure comfort while avoiding over-cooling.

National Grid administered four demand response events as part of the Ecobee and Weatherbug Home smart thermostat pilot—all during the summer months of 2014 and on days that were forecast to be especially hot. One of the four demand response events had no pre-cooling, one had one hour of pre-cooling, and two had smart pre-cooling, where the pre-cooling was optimized based on historical HVAC runtime and time-to-temperature data.

All participants of the group with HVAC optimization controls were invited to participate. While few participants opted out, Cadmus reduced the population to 30 to eliminate outliers, missing data, and other anomalies. . Key study findings include the following:

- Across all four events, an average estimated cooling runtime reduction of 7.9 minutes occurred in the first event hour and 3.6 minutes occurred in the second hour.
- Of the four events, the smart cooling-style demand response events had the largest impact on savings. During the two smart pre-cooling events, average estimated demand reductions of 0.847 kW and 0.267 kW resulted. Across all four events, average estimated demand reductions were 0.520 kW in the first hour and 0.472 kW in the second event hour. (Assuming an average energy efficiency ratio (EER) of 11, the average demand of each unit while running would be 4.36 kW.) We should note, however, that most hourly savings numbers were not statistically significant and that some overstatement of savings seemed likely with the highest savings number.
- In general, participants did not find events uncomfortable. The majority of participants (65% to 80%, depending on demand response event) did not notice a change in comfort level during the events. Some participants (14% to 29%) noticed the house was warmer but found the comfort level to be acceptable, and even fewer participants (0 to 8%, depending on the event) found the house to be considerably less comfortable.

The Future

The Nest and WeatherBug Home studies demonstrate the impacts smart thermostats can have on energy savings, customer comfort, and peak demand today. But what does the future look like? With the availability of smart thermostat interval data, utilities can offer whole-home energy monitoring, customized home diagnostics, and additional connected home devices to customers.

Whole-Home Energy Monitoring

Smart thermostats can be integrated with smart energy meters to display information about users' whole-home energy consumption including historical usage, estimated usage, and estimated bills directly on their thermostat. This information could increase engagement among users and result in energy-efficient behavior beyond the HVAC system.

Home Diagnostics

Smart thermostats collect small-interval data that can be used to diagnose poorly performing HVAC systems or leaky homes. They collect HVAC runtime, indoor temperature, outdoor temperature, setpoints, and system mode—often in intervals as short as one minute. By identifying opportunities for energy efficiency improvements, smart thermostats could help utilities target energy efficiency program offerings to the appropriate customers.

Home Automation

Smart thermostats are just one technology among a variety of emerging intelligent devices for the home. When these devices talk to one another, the potential for energy savings grows. Connected devices that work with smart thermostats include smart window shades, ceiling fans, and lighting. These devices can share information with one another on occupancy, light levels, and current electricity rates to optimize energy usage.

Results from a 2014 home automation market survey, including data collection nationwide, indicate that consumers are already interested in opportunities to save energy through home automation. The study found that automated energy savings was the number one reason survey respondents were considering home automation.

Conclusion

With a combined population of 1,400 participants, recent NIPSCO and Vectren smart thermostat studies provide strong evidence that smart thermostats deliver considerable savings: On average, Nest thermostats reduced heating gas consumption by 13.3% and cooling electricity usage by 14.5%.

A separate study by National Grid showed strong savings in cooling season from coupling an Ecobee Smart Si thermostat with WeatherBug Home's HVAC optimization controls: Cadmus calculated average savings of 16.5% of the cooling load. The same study helped illustrate the promise of deploying smart thermostats for demand response by conducting four demand response events. Summer demand response events that utilize smart pre-cooling appear to offer the most promise.

Participant surveys conducted as part of the National Grid study showed that the majority of participants did not notice a difference in the comfort of their homes relative to the time before participating in the program. Similarly, most participants did not notice a comfort difference in their homes during demand response events.

As utilities strive to manage their relationships with customers, meet aggressive energy-savings targets, and manage their demand to avoid peak charges from the regional grid, smart thermostats can help meet all three of these goals.

People

By engaging customers with an energy management technology they are already interested in and that is proven to reduce energy usage while safeguarding comfort, program administrators can improve programs and maintain customer participation.

Planet

Evaluations have demonstrated strong savings for smart thermostats, which translates to fewer CO2 emissions and a healthier planet. Deploying smart thermostats as part of a demand response platform can also contribute to healthier planet by providing load balancing required to support increased use of renewables.

Profits

Smart thermostats provide a platform for utilities to administer direct load control and behavioral demand response programs that can reduce peak demand. By better managing their demand, energy providers can avoid peak charges from the regional grid or reduce the need for expensive load-balancing resources.

References

Aarish, C., Rietz, A., Perussi, M., Higgins, K., Horvath, Z., Reynolds, A. “Evaluation of 2013-2014 Smart Thermostat Pilots: Home Energy Monitoring, Automatic Temperature Control, Demand Response.” Prepared by Cadmus for National Grid. 2015. http://www.cadmusgroup.com/wp-content/uploads/2016/05/Cadmus_ATC_HEM_Report_FINAL_revised_Sep_2015.pdf

Aarish, C., Perussi, M., Rietz, A., and Korn, D. “Evaluation of the 2013–2014 Programmable and Smart Thermostat Program.” Prepared by Cadmus for NIPSCO. 2015. http://www.cadmusgroup.com/wp-content/uploads/2016/05/Cadmus_NIPSCO_Nest_Report_Jan2015.pdf

Aarish, C., Perussi, M., Rietz, A., and Korn, D. “Evaluation of the 2013–2014 Programmable and Smart Thermostat Program.” Prepared by Cadmus for Vectren. 2015. http://www.cadmusgroup.com/wp-content/uploads/2015/06/Cadmus_Vectren_Nest_Report_Jan2015.pdf

CLEAResult. 2015. "Opportunities for Home Energy Management Systems (HEMS) in Advancing Residential Energy Efficiency Programs." Appendix B: Findings from 2014 CLEAResult Home Automation Market Survey. Prepared by CLEAResult for Northeast Energy Efficiency Partnership, Inc. (NEEP). 2015. http://www.neep.org/file/3434/download?token=LbSa2pM2