NAVIGANT

Memorandum

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Molly Podolefsky, Robert Fitzgerald, and Cameron Moy, Navigant Consulting, Inc.

Date: November 8, 2017

Subject: Connected Thermostats and Technology Literature Review (RES 17)

This memo summarizes Navigant's findings from a comprehensive review of literature pertaining to smart thermostats and other connected devices in residential settings. There were several goals for this study:

- Provide an understanding of the state of existing technologies and their effects on energy consumption
- Describe the likely direction of emerging and future technologies
- Outline potential future effects on home energy use and savings

The research team synthesized its findings from a wide range of sources and distilled key findings to inform the program administrators' (PA) decision whether to invest in deeper, targeted research on savings attributable to these connected devices.

Summary

Navigant's review of existing literature on smart thermostats and other connected devices revealed these products are gaining traction in the consumer market, with thermostat market share increasing most rapidly. For this reason and others outlined later in this memo, the research team recommends performing a primary research study of smart thermostat energy savings specific to Massachusetts. Energy savings have been identified for smart thermostats in different utility programs across North America, but reports from recent studies are not consistent in their findings across multiple years, climate zones, or thermostat types. Therefore, a primary research study will provide current, geographically and programmatically relevant data to further inform future decisions regarding incentivizing smart thermostat purchases by Massachusetts utility customers.

Furthermore, due to the lack of consistent data regarding other connected devices and the relatively sparse market for these products, Navigant recommends not performing a primary research study for such devices at this time. However, as the market for other connected household devices grows and the technology develops, such an updated environment could justify a primary research study in the future.

The following sections provide additional details on the findings from Navigant's comprehensive technology literature review of smart thermostats and connected devices.

Background

Smart thermostats and other connected devices rely on Internet connectivity to allow consumers to remotely monitor energy use and settings and enable devices to self-adjust and learn (e.g., advanced smart thermostats may adjust settings as they sense the customer entering a given proximity to their home). These connected devices often contain advanced computing capabilities to automate different functionalities based on a variety of factors including user preference, user proximity, temperature, and location. Based on these capabilities, smart thermostats and other connected devices provide two important channels for energy savings:

1. Provide the user immediate feedback on the device's operation, thereby enabling the user to adjust operation (some devices can even report an energy consumption estimate)

2. Enable a device to self-regulate its operation based on external factors (e.g., user preference, user location, local weather, etc.).

Energy savings from smart thermostats and other connected devices are typically achieved by allowing the device's optimization algorithms to balance operational performance (e.g., thermostat setting, refrigerator temperature, etc.) with energy consumption; this attempts to lower energy consumption and maximize savings while minimizing negative effects on the customer's experience (e.g., thermal comfort, food temperature, etc.).

Smart thermostats are a relatively mature technology, and utilities are increasingly offering them as part of energy efficiency and demand response (DR) programs. While their capabilities and enhanced features continue to expand, the savings from smart thermostats are well-researched and differentiated by product type, degree of smartness (termed *intelligence* throughout the remainder of this memo), cooling versus heating season, climate zone, and other key considerations, and new research is keeping pace with technical advances. Existing research suggests there is no one-size-fits-all approach to smart thermostat savings, as they vary along many dimensions, including climate zone, user demographics, device intelligence, make and model, etc. For this reason, continued primary research on savings from these devices is imperative, and Navigant feels Massachusetts PAs will benefit from conducting primary research on smart thermostat savings specific to their climate, customer base, and program details.

Other connected devices such as smart home security systems, smart kitchen appliances, smart lighting, and pool pumps fill a newer space in the market and are considerably less well-researched. At present, savings for many of these connected devices are based solely on manufacturer testimony or limited case studies. Little rigorous, ex post analysis of savings exists for most of these technologies. While the market for this Internet of Things (IoT) is rapidly expanding, these technologies are nascent, and the potential for savings remains an open question. Within the next several years, a select few of these other connected devices may enter the mainstream and research may verify energy and demand savings. In the interim, this is a wait-and-see market.

Smart Thermostats

In general, smart thermostats provide consumers with increased information and control over their residential heating and cooling system usage. However, many models simultaneously take the pressure off consumers by learning and optimizing for them, obviating the need for frequent consumer adjustments and interventions. Whether smart thermostats are merely connected and communicating or have advanced learning features and enhanced capabilities, the end goal is to increase customer comfort while creating energy and demand savings. HVAC systems often account for the largest part of residential electric and gas consumption; therefore, optimizing their performance and use through smart thermostats holds great savings potential. As thermostats become more diverse and offer a greater variety of smart capabilities and features, it will be important for research to document thermostat savings and account for the underlying differences between makes and models, climates, and customer characteristics driving differences in energy and demand savings.

Product and Market Overview

The primary function of a thermostat is to turn on and off an HVAC system in response to the ambient room temperature exceeding a specified threshold. However, today's thermostats vary widely in terms of their abilities beyond basic temperature control. Thermostat capabilities vary along a spectrum from manual to advanced smart:

Manual

- Provides manual temperature control

Programmable

- Allows users to program temperature setpoint schedule

Communicating

- Programmable features plus:
  - Wi-Fi-enabled to provide remote access to adjust setpoints via a smartphone or web app
  - Remote utility control of setpoints possible for DR purposes

Basic Smart and Advanced Smart

- Basic smart and advanced smart thermostats have the communicating features described above, but have additional capabilities beyond communication. Table 1 provides a list of additional capabilities known to exist in smart thermostats today. The intelligence or "degree of smartness" varies for smart thermostats. To help distinguish between smart thermostats based on intelligence, Navigant has developed a rubric based on the Smart Characteristics in Table 1.
  - Navigant defines Basic Smart thermostats as having all the capabilities of Communicating thermostats plus *one to two* additional smart characteristics from Table 1.
  - Navigant defines Advanced Smart thermostats as having all the capabilities of Communicating thermostats plus the *majority* of additional smart characteristics listed in Table 1.

Table 1. Smart Thermostat Capabilities

Additional Capabilities Commonly Available in Smart Thermostats	
Occupancy detection	Humidity control
Proximity detection	Weather-enabled optimization
Schedule learning	Free cooling/economizer capability
Heat pump auxiliary heat optimization	Behavioral encouragement features
Upstaging/downstaging optimization	Fan dissipation

While official categorizations of thermostat intelligence do not exist or are not uniformly accepted, Navigant finds using the above spectrum to characterize intelligence is instructive. Because different studies find savings vary widely based on the degree of thermostat intelligence, this is a critical differentiator to address when generalizing or predicting savings from smart thermostat programs. Today's smart thermostats incorporate cutting-edge computer technology and utilize machine learning and other advanced learning algorithms to become more effective and more efficient when learning the consumer's schedule, habits, and preferences, enabling many of the smart characteristics listed in Table 1.

Although there are many programmable and connected thermostats available to consumers, there are still relatively few advanced smart thermostats on the market. Nest, ecobee, and Honeywell currently produce the most popular advanced smart thermostats, as shown in Table 2.

Table 2. Leading Advanced Smart Thermostats by Maker

Vendor	Vendor Status	Latest Product Update	Newest Features
Nest	Advanced Smart	Learning Thermostat 3rd Generation *September 2015*	• Automatically adapts temperature setting based on learned scheduling behavior • Integrates with suite of Nest devices including Nest Protect and Nest Cam, enhancing home security • Proximity technology[1] adjusts settings based on customer's distance from home through smartphone location
ecobee	Advanced Smart	ecobee4 *May 2017*	• Automatically adapts temperature based on current and future weather conditions • Room sensor manages hot and cold spots • Includes Amazon Alexa voice-activated functionality (e.g., can be used to adjust temperature, order groceries, read the news, etc. through voice commands)
Honeywell	Advanced Smart	Lyric T6 Pro *December 2016*	• Geofence technology[2] adjusts settings based on customer's proximity to home using smartphone location • Designed as a connected device platform to integrate with other Lyric smart home devices

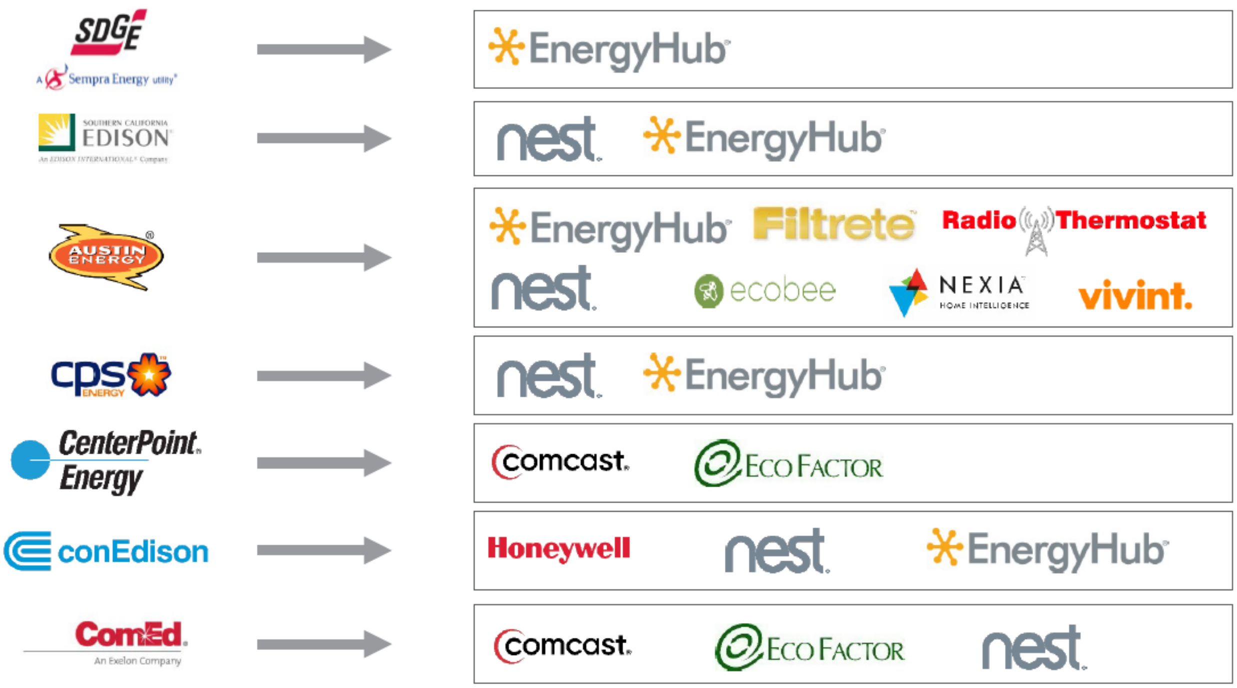
Source: Navigant research

In contrast to smart thermostats that perform internal processing, another class of smart thermostat exists that use a connected thermostat but with most data processing performed on a remote server. These remotely controlled thermostats are not directly marketed or sold to consumers; rather, they are distributed and run through cooperation with utilities. Examples of such partnerships are shown in

[1] The "proximity technology" used by Nest is effectively the same concept as Honeywell's "geofence technology", using location reported by a smart phone to determine if a resident is at home, nearby, etc.
[2] The "proximity technology" used by Nest is effectively the same concept as Honeywell's "geofence technology", using location reported by a smart phone to determine if a resident is at home, nearby, etc.

Figure 1[3]. Energy management companies (such as EnergyHub, AutoGrid, and Whisker Labs) support utilities with Bring Your Own Thermostat (BYOT) programs, and provide many valuable services: vendor onboarding and contracting, automated customer enrollment, customer communications, harmonization of data formatting and data management across multiple vendors to facilitate utility customer access to and use of data, and demand response dispatch and reporting.

Figure 1: Utility and Vendor Partnerships Identified by Navigant Research in 2016



These remotely controlled thermostats have several purposes, but are used primarily for demand response. For example, National Grid in MA currently offers a Wi-Fi Thermostat Demand Response (DR) program through which it partners with Nest to offer a Rush Hour Rewards program, and with Ecobee and Honeywell to offer a ConnectedSolutions program, both aimed to reduce customer peak demand.[4] Commonwealth Edison, Kansas City Power & Light Company, and Salt River Project have partnered with Nest to implement a smart thermostat Rush Hour Rewards DR programs. Other examples of smart thermostat demand response programs include Old Dominion Electric Cooperative's Smart Response thermostat program with EnergyHub, Austin Energy's Power Partner Thermostat and Energy Cycling programs with ecobee, and Southern California Edison's Save Power Days program. Furthermore, Arizona Public Service (APS) is currently planning a BYOT-style demand response program to be implemented in 2018, while Duke Energy is working on a BYOT residential demand response program to complement its commercial programs. Remotely controlled thermostats can also be pre-programmed with time-of-use (TOU) rates, as exemplified by Nest's Time of Savings program. Upon a customer's enrollment in the program, a utility will share its customer's electricity rates with Nest, and the customer's Nest Learning Thermostat will use electricity price changes to automatically adjust during peak pricing hours. Every time the season and the customer's electricity rates change, Time of Savings will re-optimize the customer's temperature schedule and continue learning (and improving) over the course of several weeks. Though Nest is

[3] Feldman, B. Lawrence, M. (1Q 2016). p. 9. "Bring Your Own Thermostat Demand Response". Navigant Research.
[4] 2016 Residential Wi-Fi Thermostat DR Evaluation Final Report, prepared for National Grid by Navigant, April 12, 2017.

one of the more prominent vendors offering this capability, Lux and other thermostat manufacturers offer partner utilities similar TOU rate pre-programming options.

Currently, "Mass Save[5]" incentivizes the purchase of thermostats through two channels. First, there are rebates for programmable thermostats ($50 rebate) and wireless-enabled thermostats ($50-100 rebates, depending on the manufacturer)[6]. Second, Mass Save offers the Honeywell Lyric Round or the Building 36 Wi-Fi thermostats to be directly installed to a customer's residence by technician for a total customer cost of $50[7]. Both direct-install thermostats offered by the program are smart thermostats that offer similar functionality to other leading residential smart thermostats.

Energy Savings

As discussed above, energy savings from smart thermostats, relative to non-smart thermostats, are generally realized through two channels:

1. Providing the user immediate feedback on the device's operation, thereby enabling the user to adjust operation (some devices can even report an energy consumption estimate)

2. Enabling a device to self-regulate its operation based on external factors (e.g., user preference, user location, local weather, etc.).

By accounting for room occupancy, proximity of the consumer to home, work schedules, weather variables, and through other capabilities, advanced smart thermostats can significantly reduce energy use relative to simple programmable or communicating devices and basic smart thermostats.

The difference between basic smart and advanced smart thermostats can be exemplified by comparing how a specific model of basic smart thermostat, the Aprilaire Model 8620W WiFi Thermostat, and an advanced smart thermostat, say the ecobee4, would operate under specific hypothetical conditions. The Aprilaire 8620W basic smart thermostat measures humidity and can run the air conditioning system to reduce the humidity to a comfortable level. However, this function must be manually enabled or disabled, meaning that the humidity could be unnecessarily controlled while no one is home. Similarly, the ecobee4 advanced smart thermostat can measure and control a home's humidity, but unlike the Aprilaire 8620W, it can be configured to only maintain comfortable conditions when someone is at home. In this way, the advanced smart thermostat saves greater energy compared with the basic smart thermostat.

Navigant identified 28 studies that report energy savings associated with the installation and use of smart thermostats within the United States. Of these studies, 22 are based on advanced smart thermostats, while the remaining six are based on basic smart thermostats. The aggregated metrics of identified energy savings are shown in Table 3, while further information on the energy savings identified in secondary research is available in the attached workbook.[8] Overall, advanced smart thermostats have higher savings relative to basic smart thermostats. While average heating and cooling savings values for basic smart thermostats range between 4% and 10%, symmetric average values for advanced smart thermostats range from 8% to 12%. The wide variation in verified, researched savings values within every category (Table 3) is notable, but unsurprising due to the

[5] Mass Save is a collaborative of Massachusetts' natural gas and electric utilities and energy efficiency service providers, including Berkshire Gas, Blackstone Gas Company, Cape Light Compact, Columbia Gas of Massachusetts, Eversource, Liberty Utilities, National Grid and Unitil.
[6] https://www.masssave.com/en/saving/residential-rebates/wireless-and-programmable-thermostats/
[7] https://www.masssave.com/en/saving/residential-rebates/wireless-thermostat-installation-incentive/
[8] As part of this memo, the research team has included a comprehensive annotated bibliography in Excel workbook format: for easy reference and complete information, see the file Wifi TStat Tech & Review Workbook.

large number of variables involved in each study (e.g., climate, HVAC type, building shell efficiency, etc).

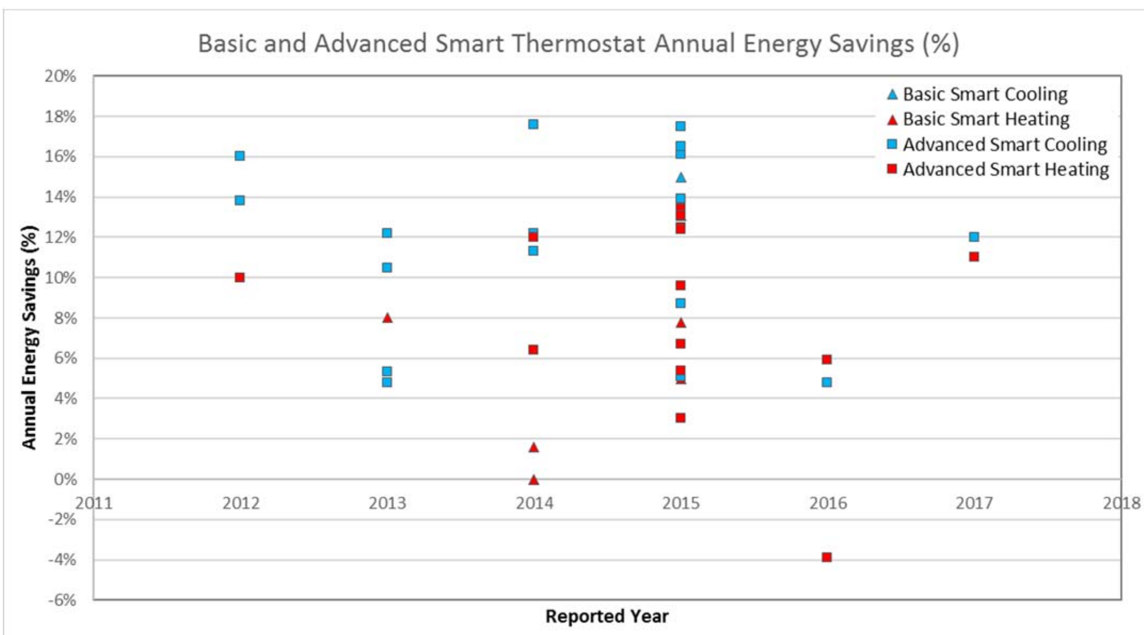
Table 3. Researched Heating and Cooling Savings Values by Thermostat Intelligence Level[9]

	Basic Smart Cooling	Basic Smart Heating	Advanced Smart Cooling	Advanced Smart Heating
Average Energy Savings	9.37%	4.48%	11.66%	8.39%
Maximum Energy Savings	15.00%	8.00%	17.60%	13.40%
Minimum Energy Savings	0.00%	0.00%	4.80%	-3.90%
Number of Data Points included	3	5	17	14

Source: Navigant research

Energy savings are plotted in Figure 2, separated out into heating and cooling energy for both basic smart and advanced smart thermostats per year. The energy savings attributed to cooling are plotted in Figure 3 for each climate zone covered by the reported study; a corresponding plot for heating is shown in Figure 4. From these plots, it is apparent that there is no relationship between the year of reported savings and the energy savings. Further, there does not appear to be a relationship between energy savings and climate zone covered by the reported study.

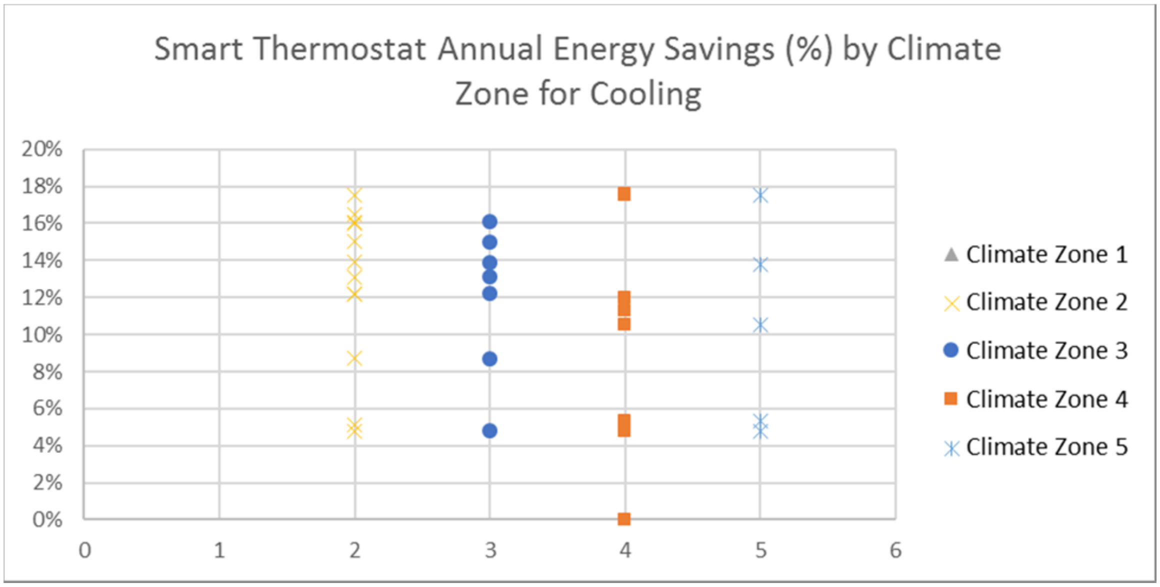
Figure 2. Researched Smart Thermostat Heating and Cooling Load Savings by Study Year



Source: Navigant research

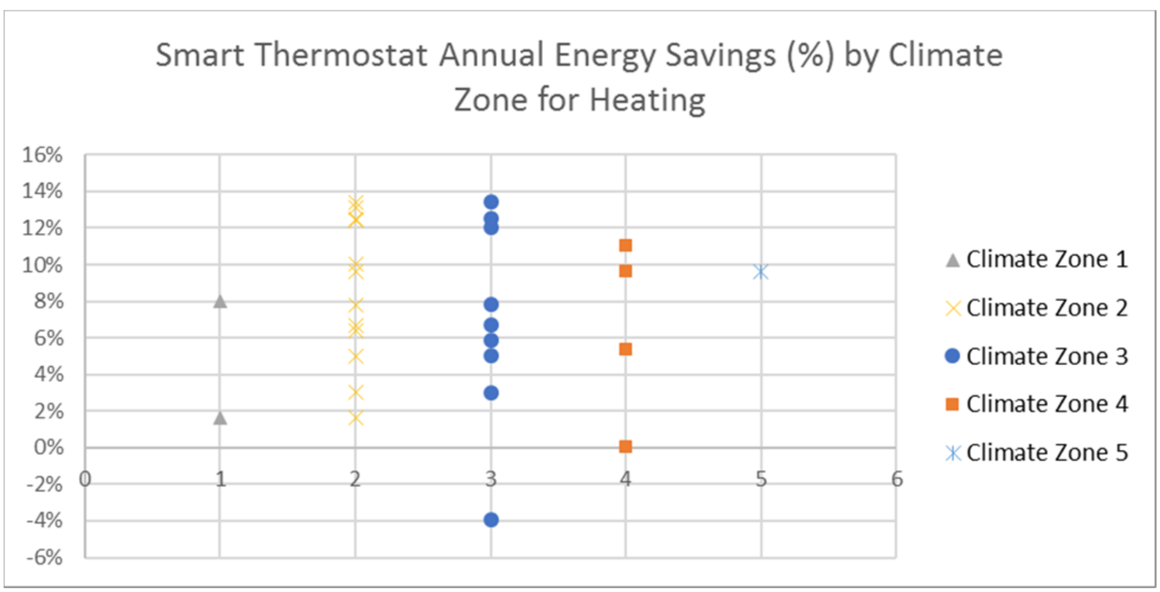
[9] These values represent researched energy savings values as a percentage of heating or cooling load rather than as a percentage of whole home energy use.

Figure 3. Researched Smart Thermostat Cooling Load Savings by Climate Zone



Source: Navigant research

Figure 4. Researched Smart Thermostat Heating Load Savings by Climate Zone



Source: Navigant research

Figure 2, Figure 3, and Figure 4 explore differences in smart thermostat savings by heating and cooling loads by year and climate zone[10]. These plots demonstrate no clear relationship between savings and either year or climate zone for either heating or cooling loads. While this does not imply there is not a relationship between climate and thermostat savings, for instance, it does suggest that there may be other factors differentiating between various studies (make and model of thermostat, program parameters, population demographics, etc.) that obscure this relationship. Similarly, technologies may be improving, which leads to greater savings over time. However, this relationship may also be overpowered by other factors differentiating the studies. In other words, the studies are likely not apples-to-apples comparisons of thermostat performance in different years or climate zones. In this case, the research team cannot draw a clear relationship between these factors and savings.

Other Connected Devices

Beyond smart thermostats, a wave of smart and connected devices, often referred to as IoT (the "Internet of Things"), is flooding the market with everything from connected kitchen devices and home security systems to connected lighting and pool pumps. A growing trend is interconnectivity between these smart devices so that a smart thermostat or other connected device may act as a central hub for a suite of residential connected devices from a smart refrigerator to smart lighting and smart home webcams. Because this market is young and rapidly expanding, the range of smart connected devices is increasing rapidly, and the degree of interconnectivity between different devices and platforms is also quickly evolving.

As this market is relatively new, little verified savings research exists on these products, leaving considerable room for speculation as to which products will eventually be winners and losers in terms of generating reliable energy savings. In fact, some connected devices may even increase energy use rather than decrease it. Moreover, because this market is undergoing rapid evolution, savings values generated for one type of connected device today (e.g., smart refrigerators) might be obsolete within a year as the technology matures. In Navigant's view, the best approach to other connected devices is to wait and see how this market develops and reassess the potential for savings regularly.

Product and Market Overview

Although various types of Internet-connected household devices have been commercially available for several years, consumers have been relatively slow to adopt these products. Connected devices currently available in the market include dishwashers, clothes dryers, toasters, refrigerators, lighting, home security devices and a host of other technologies.

Connected lighting is one example of a connected device market that is growing rapidly. Some connected lighting systems require a separate hub for operation, while others simply connect to a household's Wi-Fi network. Consumers can then control these systems using a variety of home connectivity systems such as Apple HomePod, Amazon Echo, or Google Home. The connectivity of lighting can provide the user the opportunity to adjust the brightness and color, as well as remotely schedule and program when the lighting turns on or off. Rapidly falling LED prices have facilitated adoption of these new connected lighting technologies. Moreover, LED light bulbs tend to replace products with short lifespans (CFLs, incandescent bulbs, etc.), so consumers face purchase decisions more frequently. Additionally, residential settings tend to have numerous light sockets thus, adoption of the technology can occur gradually within a household. As a result, connected lighting is gaining market traction more quickly relative to most other connected devices.

[10] AIA Climate Zones — RECS 1978-2005. https://www.eia.gov/consumption/residential/maps.php

Connected plugs are another example of connected devices that are gaining market traction relatively rapidly, though their overall market penetration remains low at this point. While they vary in terms of functionality, primarily they provide an interface between a power outlet and a device powered by that outlet. Once in place, the connected plug connects to the Internet over a Wi-Fi connection and allows a user to enable or disable power to the plugged-in device. These devices are available in a single-plug as well as a multi-plug (i.e., power strip) format. Although connected plugs largely offer convenience in toggling the power of appliances, it is worth noting that connected plugs offer the ability to completely turn off a powered device rather than placing it in a low-power standby mode, offering additional energy savings potential. This mechanism of energy savings is similar to Advanced Power Strip (APS) Tier 2 functionality, but whereas APS Tier 2 powers down devices automatically based on sensory input, connected plugs often require an intentional command (either in real time or via a schedule) from a user to power a device down. Much like connected lighting, connected plugs are gaining popularity in the consumer market due to their relatively low cost. Most connected plugs currently available appear to be in the single-plug rather than the multi-plug format. Retail pricing both formats falls between $15 and $40 per unit, which is noticeably cheaper than devices marketed as Tier 2 APS. While connected plugs are a technology to watch, they still have relatively low market penetration.

Beyond connected lighting and plugs, many different types of connected household appliances are being marketed to consumers, including refrigerators, dishwashers, toasters, clothes washers, clothes dryers, domestic hot water heaters (DHWs), and range-ovens. The longer lifespan and higher prices of these appliances, as well as the relatively limited benefit provided by their connectivity, have slowed consumer adoption of these technologies. Currently, only a few manufacturers offer connected versions of their appliances, and the connectivity of these types of products is typically limited; they notify users about the appliance’s current state (e.g., refrigerator temperature, laundry load completion, oven preheating completion) and are not focused on energy savings. Few reports are currently available on energy savings for these devices, and the available literature does not provide a strong correlation, either positive or negative, between connectivity and energy savings. These connected devices are being adopted by consumers at a much slower pace relative to connected lighting.

Energy Savings

While energy savings are often advertised as a major advantage for smart thermostats, other connected household devices tend to focus more on using their Internet connectivity to offer expanded functionality and convenience to the consumer. For example, a connected clothes washer could alert a user via smart phone message that their wash cycle is finished. Such a feature provides increased convenience but does not deliver energy savings. While these products are focused on providing expanded functionality to the consumer, they can also provide energy savings. For example, a connected refrigerator can send an alert to a smartphone indicating that its door is ajar or a connected oven can send an alert indicating that it is preheated to the desired temperature. For the former, the refrigerator operates more efficiently when its door is closed; for the latter, reducing the amount of time that a preheated oven is empty reduces the overall energy consumption. Similarly, connected lighting products hold potential for energy savings by allowing the customer to remotely adjust lighting levels, or turn lights off when not in use, even when they are not at home.

While the above findings suggest the potential for energy savings from some household connected devices beyond thermostats, Navigant’s literature examination identified few recent studies reporting energy savings for connected household devices beyond thermostats. Many of the studies we identified focused on the energy savings associated with installing a home energy monitoring system in a household, wherein energy savings are realized by influencing user behavior, rather than isolating energy savings attributable to individual connected devices. Unfortunately, of the few studies examined that reported energy savings, even fewer reported savings for specific connected devices. Those that did, reported relatively low (<5%) energy savings. The takeaway message here is that most of these connected device markets are not mature, the technologies are still evolving and have not penetrated a large portion of the consumer market. As a result, researched studies on savings for these devices are limited at this point in time, though we expect more studies to emerge as these technologies continue to gain market traction in the coming years. Further information on the energy savings identified in secondary research is available in the attached workbook.

It is also important to understand that some connected devices will likely be aimed at demand savings or load shifting goals rather than energy savings. A good example is electric water heaters, which some utilities have begun deploying in pilot studies to gauge their ability to shift load from less-desirable to more-desirable times of day, reducing peak load or minimizing the impacts of solar "duck-curve" penetration. Few if any studies estimate peak demand impacts for these connected technologies, but this is one secondary research area to monitor. Navigant has modeled the potential cost savings for a specific region of the Southwest US and determined that demand shifting using smart thermostats can deliver annual bill reductions of 2.2% to 3.8% depending on the specific time of use (TOU) rate structure used. Furthermore, although it does not provide direct cost-savings figures, a 2013 impact estimation of TOU rates in Ontario, Canada (Figure 5)[11] suggests that TOU rates effect a mixture of load shifting and energy conservation, depending on the time of year.

Figure 5: Impact Estimation of Residential TOU Rates (Ontario, Canada)

		Avg kWh Impact* (Entire Period)	Avg. kW Impact (Per Hour)	Average % Impact
Summer (Jun, Jul, Aug)	On-Peak	-0.263	-0.044	-3.3%
	Mid-Peak	-0.173	-0.029	-2.2%
	Off-Peak	0.156	0.013	1.2%
	Off-Peak Weekend	0.556	0.023	1.9%
Summer Shoulder (May, Sept, Oct)	On-Peak	-0.132	-0.022	-2.2%
	Mid-Peak	-0.103	-0.017	-1.5%
	Off-Peak	0.167	0.014	1.5%
	Off-Peak Weekend	0.362	0.015	1.4%
Winter (Dec, Jan, Feb)	On-Peak	-0.300	-0.050	-3.4%
	Mid-Peak	-0.395	-0.066	-3.9%
	Off-Peak	-0.420	-0.035	-2.5%
	Off-Peak Weekend	-0.468	-0.020	-1.2%
Winter Shoulder (Nov, Mar, Apr)	On-Peak	-0.136	-0.023	-2.1%
	Mid-Peak	-0.177	-0.030	-2.3%
	Off-Peak	-0.144	-0.012	-1.1%
	Off-Peak Weekend	0.140	0.006	0.5%

Rows shaded in gray are not statistically significant at the 95% level.
**Impact on average energy consumption per customer, per period, per day (On-Peak, Mid-Peak, Off-Peak) or per week (Off-Peak Weekend)*

11 Time of Use Rates in Ontario. Part 1: Impact Analysis. 2013. P. v. https://www.oeb.ca/oeb/_Documents/EB-2004-0205/Navigant_report_TOU_Rates_in_Ontario_Part_1_201312.pdf

Opportunities for Further Investigation

Navigant's review of existing literature on smart thermostats and other connected devices revealed these products are gaining traction in the consumer market, with thermostat market share increasing most rapidly. While the variety of smart thermostat devices available has grown, advanced thermostat penetration is largely limited to three major manufacturers: Nest, Honeywell, and ecobee. Increasingly these products are being used as central hubs communicating with a suite of smart products within households. Navigant and other evaluators should take this into account in future evaluations when this type of use becomes more common.

Smart Thermostat Recommendations

Considering the team's findings, Navigant suggests a near-term primary research study on smart thermostat savings. A similar study targeting Wi-Fi programmable controllable thermostats was published in September 2012 for the Electric and Gas Program Administrators of Massachusetts[12]. Although Navigant is not aware of recent smart thermostat studies focused on energy savings in New England, a utility in Connecticut is currently piloting a Residential Demand Reduction Control (DRC) program for 2017[13]. National Grid has recently completed pilot programs in New England, but one was heavily focused on examining smart thermostat demand reduction[14], and another was focused on TOU rates in general rather than on the energy savings of smart thermostats[15]. Existing research suggests that verified savings estimates vary considerably by program, device intelligence, climate/region, and program parameters. Therefore, while considerable research on savings exists, it is not easy to extrapolate savings from one study to a new program or utility. For this reason, Navigant considers there to be significant value to the Massachusetts PAs in conducting their own primary research on thermostat savings specific to the state of Massachusetts.

Proposed Primary Research Study

Navigant's analysis of smart thermostat market trends and existing researched savings by thermostat type suggests there is considerable room for more research. The team notes that savings from thermostats vary considerably according to maker and device type, thermostat intelligence, customer behavior, and other considerations. Special considerations would include the following:

- Climate in Massachusetts
- Types of cooling systems in place in Massachusetts homes
- Whether thermostats are installed through a bring your own thermostat approach versus direct installs
- Make and model of thermostat and device intelligence

Given all these and further utility- and region-specific considerations, it is reasonable to believe that Massachusetts smart thermostat savings may differ from existing researched impact results. Hence, Navigant concludes that primary research is warranted. Based on initial discussion with PAs, this

---

[12] "Wi-Fi Programmable Controllable Thermostat Pilot Program Evaluation". September 2012. http://ma-eeac.org/wordpress/wp-content/uploads/Wi-Fi-Programmable-Controllable-Thermostat-Pilot-Program-Evaluation_Part-of-the-Massachusetts-2011-Residential-Retrofit-Low-Income-Program-Area-Study.pdf
[13] "Eversource Connecticut DR Pilots Overview and Status". p. 8. http://www.ct.gov/deep/lib/deep/energy/ces/Eversource_Demand_Resources_Presentation_10-27-16.pdf
[14] "2016 Residential Wi-Fi Thermostat DR - Evaluation Final Report". 2017. Prepared for National Grid.
[15] Seiden, K. et al. "National Grid Smart Energy Solutions Pilot - Final Evaluation Report". 2017 Prepared for National Grid.

study should separately investigate savings for both HES and MF programs, potentially investigating savings differences by building type as well.

To complete a successful primary research study of smart thermostat savings in Massachusetts, Navigant would need to acquire both pre- and post-data for smart thermostat recipients across the PAs that have active thermostat programs. One option for the analysis, which the research team has used successfully in other regions, would be to define one 12-month period as the install period, define the subsequent 12-month period as the post-period, and the 12 months prior to the install period as the pre-period. The team suggests using a matching methodology approach where a control group composed of non-participants drawn from the general population is constructed based on similarity of energy use in the pre-period. Matching would then need to be conducted based on energy use during the 12 months preceding the pre-period. Because some programs expose participants to multiple measures simultaneously, the research team would likely need to remove thermostats from the analysis if they were installed simultaneously with other measures.

Our team suggests a regression analysis-based approach to estimating impacts from smart thermostats. Though details of the regression model are subject to change and will be adjusted and modified to meet the needs of this specific evaluation, the model specification in Equation 1 describes a best practice base model of thermostat savings Navigant has applied to analyzing smart thermostat savings in other utility service territories.

Equation 1. Smart Thermostat Impact Model

$$ADU_{kt} = \alpha_k + \beta_1 HDD_{kt} + \beta_2 CDD_{kt} + \beta_3 post_t + \beta_4 post_t * HDD_{kt} + \beta_5 post_t * CDD_{kt} + \beta_6 treat_{kt} * HDD_{kt} + \beta_6 treat_{kt} * CDD_{kt} + \beta_7 post_{kt} * treat_{kt} + \beta_8 post_{kt} * treat_{kt} * HDD_{kt} + \beta_9 post_{kt} * treat_{kt} * CDD_{kt} + \varepsilon_{kt}$$

In the above model, impacts are captured by the treatment variable (treat) interacted with the post period and associated weather variables, such as HDD and CDD (heating degree days and cooling degree days).

Other Connected Devices Recommendations

Navigant does not currently suggest the PAs undertake primary research on savings from other connected devices, even though many hold the potential for savings—particularly connected lighting, pool pumps, and water heaters. The research team feels it is too early in the market to warrant evaluation of savings from these and other connected devices in the immediate term. Navigant suggests reviewing existing literature on these other connected devices periodically to assess how many new research-based savings reports are available. In our experience, once several researched savings reports are made public and demonstrate savings for a connected product, it may warrant piloting and primary savings research by the PAs.