Memorandum

To: Bonnie Watson, Bonneville Power Administration

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Date: October 16, 2018

Subject: TO 017 – Smart Thermostat Market Characterization to Inform Market Modeling

Introduction

This memo summarizes the findings of the Cadeo TO 17 research team (comprising Research Into Action, SBW Consulting, and Cadeo) into the current state of the residential thermostat market in the Northwest. The main purpose of this research was to garner insights and provide clarity into the relatively new and complex market for smart thermostats to determine if and how savings for these devices might be incorporated into the Residential HVAC Momentum Savings Model. An Excel-based Technology Matrix accompanies this memo.

To structure the inquiry, BPA developed research questions covering four main topic areas. Table 1 presents the topic areas, research objectives, and research questions addressed by this study.

Table 1. Areas of Inquiry

Market Aspect	Research Objective	Research Question
Defining technologies in the market	Sort through the various definitions of thermostats being used in the market and ascertain which thermostat features drive savings	• What are all the different options in the market and what are the key features of those measures that impact energy consumption? • What are the definitions or "buckets" that different thermostats can fall into that matter for the modeling work? • What is the priority for features that we should be paying particular attention to? (such as, "the majority of savings comes from these key features which matter most")
Energy savings	Review and assess the reliability and accuracy of energy savings for the Northwest market and understand the applicability to the momentum model	• Which thermostats save energy and how much? Which ones don't save energy and why? • Why is it that some people use more energy when they get a new smart thermostat? • What is the overlap between CC&S/PTCS and thermostat savings? Are thermostat savings negated if paired with CC&S?

Market Aspect	Research Objective	Research Question
		• Are there high-level notable issues for modeling that we should be aware of around the differences between the ENERGY STAR specification and BPA program specifications? • What do we need to be aware of from a savings perspective that we should watch out for when it comes to modeling thermostats?
Market dynamics	Understand ways the smart thermostat market is similar to and different from the traditional HVAC market and assess saturation and growth	• What do the supply chain and decision chain each look like and what are the major channels for each? • How do the technologies compete with each other? • What is the Northwest saturation of the different thermostat technologies? What do the details of the RBSA II tell us about where these units are going and what they are paired with? • What does the growth trend look like in the Northwest for the different technologies? What's moving, and what's not? • What market data in the Northwest exists? (e.g., has NEEA or anyone been collecting sales data on this, or can we get it directly from the manufacturers)
Compatibility	Better understand smart thermostat compatibility issues with certain HVAC equipment	• What are the compatibility issues with smart thermostats? • What has been done to assess the compatibility issue? • Are there any trends indicating compatibility issues will be resolved in the future?

Methodology

The research team conducted a detailed literature review coupled with in-depth interviews of market actors for this study. For the literature review, the research team assessed 33 evaluation reports, white papers, conference papers, and other materials related to smart thermostats. Appendix A includes a list of all secondary sources. For the in-depth interviews, the research team conducted 11 interviews with a mix of thermostat market actors including: (1) manufacturers, (2) regional efficiency organizations, (3) evaluation contractors that have conducted smart thermostat evaluations, and (4) the Bonneville Power Administration (BPA) program planning staff (see Table 2).

Table 2. In-Depth Interviews Completed

Contact Type	Number Completed
Manufacturers	3
Regional Efficiency Organizations	4
Evaluators	3
BPA	1
Total	**11**

The research team conducted each of the interviews over the telephone. Each interview lasted approximately 45 minutes.

In addition to this memo, the research team also developed a companion Excel file that is a classification and summary of features of leading thermostat technologies in the market and a listing and summarization of literature that included energy savings findings for smart thermostats.

Key Findings

Summary

The most important overall finding is that there are energy savings for one category of thermostats containing a select few models (Nest Learning and E, ecobee 3 and 4, Cor TP-WEM01-A, and Bryant T6-WEM01-A). The research team refers to this category as “advanced smart thermostats” because they have features that differentiate them from the rest of the market, such as on-board occupancy sensing, heat pump optimization, and algorithms that learn occupant behaviors and optimize thermostat settings accordingly. Also, this category of advanced smart thermostats is the only category that has robust research that provides proven energy savings—one of the key requirements for eligibility in BPA programs. No research was found that assesses energy savings by thermostat features, so the best that can be done at this point in time is to use savings values for the category as a whole. The research team proposes using the energy savings values by system type and climate zone contained in the *Residential Connected Thermostat Workbook* (RTF 2016). These values should be considered placeholder values for momentum savings modeling purposes until more data becomes available or the RTF measure advances from the planning stage.

The remainder of this Key Findings provides additional details and summarizes results by research objective.

Defining Technologies in the Market

- The term “smart thermostat” is used ubiquitously in the industry, but rarely is the term defined. In fact, a synthesis of the literature shows that different organizations have different definitions. BPA and the Energy Trust have the most restrictive definition, focusing on a small handful of smart thermostats with advanced features and have proven energy savings. These include the Nest Learning and E, ecobee 3 and 4, Cor TP-WEM01-A, and Bryant T6-WEM01-A. The RTF and

Residential Building Stock Assessment (RBSA II) smart thermostat category[1] are the next most stringent, capturing models that have all the features of programmable thermostats and connected thermostats (thermostats with Wi-Fi capabilities), but also have geofencing or occupancy sensing from non-onboard sensors and offer basic demand response capabilities. This category includes models such as the Honeywell Lyric, Honeywell T6 Pro, and the Lux models. Finally, the RBSA II Wi-Fi category, Puget Sound Energy, and ENERGY STAR are the least stringent specifications which focus on the communicating abilities offered by Wi-Fi. The Honeywell T5, Emerson Sensi, and Lux Geo are examples of these thermostats.

- Based on this research, the team recommends that the HVAC market modeling team group thermostats into 6 definitional bins. These bins are shown in Table 3.

Table 3. Thermostat Categories

Category	Research Team Definition
Line Voltage	• Thermostats that are in line with and directly switch system power (120 or 240 volts) • Used for electric space heaters such as baseboard heaters or a direct-wired electric furnaces
Manual	• Simple thermostats that regulate the HVAC system, where changes in temperature need to be made by manually adjusting the device
Programmable	• Thermostats where the occupant can set schedules and setbacks • Displays temperatures and operating modes
Connected	• Thermostats that do everything a programmable thermostat does, but also have Wi-Fi capabilities • Most offer an online dashboard or mobile app to control the device and report usage characteristics
Smart	• Thermostats that incorporate everything programmable and connected thermostat do, but also supports proximity sensing to indirectly detect occupants by external device (geofencing) or optional sensors that can be added to the thermostat • Basic demand response capabilities
Advanced Smart	• Thermostats that incorporate all features of programmable, connected, and smart thermostats but also have occupancy sensing directly onboard the device • Heat pump optimization • Algorithms that learn occupants' behaviors and characteristics of the structure and adjusts the device accordingly to improve scheduling and performance • Proven energy efficiency savings

Source: Adapted from CLEAResult, 2018

[1] Note that the RBSA II has two categories of thermostats relevant to this memo: "smart" and "Wi-Fi." This instance refers specifically to the RBSA II Smart thermostats; the next mention refers specifically to the RBSA II Wi-Fi thermostats.

- It is the research team's opinion based on discussions with thermostat manufacturers, that a ranking of the savings mechanisms that drive energy savings, by decreasing degree of potential impact on energy savings, is: (1) on-board occupancy sensing, (2) heat pump optimization, (3) learning algorithms, (4) proximity sensing (if setup and used correctly), and (5) scheduled setbacks. However, it should be noted that the research team did not find any studies that examined energy savings by features. Table 4 shows the thermostat categories, indicating what features they have as well as the estimated market share represented by each.
- When looking at the overall smart (including advanced smart) and connected thermostat market, the leaders in the industry are Nest, ecobee, and Honeywell. The contenders are several firms offering thermostat optimization services such as WeatherBug (now Whisker Labs), EnergyHub, and EcoFactor, as well as some traditional HVAC control manufacturers such as Schneider Electric, Carrier, and Emerson. The challengers are companies such as Trane and Lux.

Table 4. Energy Savings Features by Thermostat Type

Thermostat Category	Features: Energy Savings Potential LOW → HIGH					Example Products	Percent of Installed Stock (2016)[1]
	Scheduled Setbacks	Proximity Sensing (Geofencing)	Learning Algorithms	Heat Pump Optimization	(On-Board) Occupancy Sensing		
Line Voltage						Honeywell YCT410B1000/U	Unknown[2]
Manual						Honeywell RTH5100B	46%
Programmable	X					Honeywell RTH7600D, Emerson P210	47%
Connected	X					Lux Geo, Honeywell T5	1%
Smart	X	X				Honeywell Lyric, Lux Kone	6%[3]
Advanced Smart	X	X	X	X	X	Nest E and Learning, ecobee 3 and 4	

[1] Data Source: Analysis of RBSA II data.

[2] The RBSA II data did not allow the researcher to distinguish line voltage thermostats.

[3] While the RBSA II data does provide the researcher some ability to distinguish between connected (wi-fi) and smart thermostats, because of large amounts of missing data, it does not provide the granularity needed to distinguish between smart and advanced smart thermostats. Also note that the RBSA II report shows a saturation of 7% for smart /wi-fi category (NEEA 2018, p. 29 and Table 152). The 6% reported here is based on a re-analysis of the data by removing the Wi-Fi enabled category from the sum.

Energy Savings

- Of the 11 evaluation reports that the team reviewed, the clear majority show that there are energy savings from advanced smart thermostats. However, several factors should be considered when synthesizing the results. First, there is notable variability in savings across the available reports due to *device-related issues,* which include different thermostats, product feature sets, different learning algorithms, and periodic updates to device software. All these issues threaten *reliability*, or the ability to attain the same results again if the research were conducted under the same constraints, and *accuracy,* or the ability to derive the correct savings estimate. Second, there is notable variability between evaluation studies due to *study-related issues* such as different climate zones, different system types, different study designs, and different methodologies for estimating energy savings. All these latter issues threaten *generalizability,* or the applicability of results to the Northwest region. The Regional Technical Forum (RTF) recognizes many of these factors in its Residential Connected Thermostats and Services Research Strategy (RTF 2016).
- The two pilot studies that are most relevant to the Northwest provide rather comparable results. The first study, conducted by BPA and Franklin PUD (Kelsven, Weber & Urbatsch 2016), provided findings showing 745-955 kWh annually saved per thermostat, which was equivalent to 4% of total annual consumption and 12% of annual heating and cooling load in the evaluated homes. This compares to the first Energy Trust heat pump project (Apex Analytics 2014), which provided findings showing 781 kWh annually saved per thermostat, equating to 4.7% of total consumption and 12% of heating load in the evaluated homes. Also, the RTF Residential Connected Thermostat savings values are in-line with both regional studies.[2] However, it is important to note that the connected thermostat measure is in the "planning" category due to uncertainties with the savings, and the measure has a November 30, 2019 sunset date.
- Though there is significant variability in savings estimates across all the evaluation studies reviewed for the project, the results of the two regional studies and RTF measure specification are quite consistent. Given this, it is the research team's position that the best values to use as for estimating residential advanced smart thermostat momentum savings for the Northwest is the RTF savings values by system type and climate zone. For details, see the *Residential Connected Thermostat Workbook* (RTF 2016). However, these values should be considered placeholder values until more research becomes available or the RTF measure advances from the planning stage.

Market Dynamics

- The smart and advanced smart thermostat market supply chain is new and different from the traditional HVAC controls market where HVAC controls flow from manufacturers to distributors to the contractors who install the devices. In contrast, those interviewed for this project agreed that smart thermostats reach residential customers through a number of channels. In descending order of channel size, these include: (1) brick-and-mortar retail, (2) online retail, (3) contractors

[2] Note that the RTF measure is in-line with the regional studies because estimates from Energy Trust evaluations were used to develop estimates for the RTF measure.

and builders (via traditional distributors), (4) other providers such as security dealers, telecommunications and broadband service providers, electricity providers, etc., and (5) energy efficiency programs.[3]

- The leading manufacturers (Nest, ecobee, and Honeywell) state that they compete directly with each other even though prices vary across leading models. Two of the manufacturers developed thermostats (Nest E and ecobee 3 lite) that target people preferring a lower price point, but still wanting a smart thermostat. That said, because less-informed consumers do not typically know what they are looking for in terms of a thermostat, smart thermostat competition is also *all* thermostats in the market. Some manufacturers' thermostats have no competition because the only thermostats compatible with certain HVAC systems are made by the system manufacturer.
- RBSA II reported a 7% saturation for smart thermostats (see NEEA 2018, p. 29 and Table 152). However, this is a slight overestimation because it also included connected or Wi-Fi thermostats (which the research team recommends placing into the "connected" definitional grouping, as summarized in the table above). The research team's recalculation of the RBSA II data[4] suggests that the saturation of smart and advanced smart thermostats as defined by the research team is no more than about 5.6%.[5] This is quite similar to 5.3% reported in the literature.
- The research team's re-analysis of the RBSA II data determined that of the 5.6% of the thermostats in the Northwest that are smart or advanced smart thermostats, about 93% are installed in single family homes; 7% in manufactured homes. The RBSA II data also shows that for cooling, smart thermostats are paired with central air conditioners (54%) or air source heat pumps (46%). For heating, RBSA II data shows smart thermostats are paired with gas forced air furnaces (54%), air source heat pumps (35%), propane furnaces (6%), electric furnaces (4%), and boilers (1%).
- Obtaining market share or growth data will be a challenge as all the interviewed manufacturers see this information as strategic and may not be willing to share.

Compatibility

- Manufacturers design smart and advanced smart thermostats to work with most conventional residential HVAC systems, including forced air furnaces, central AC, and air source heat pumps. Multiple stages of heating and cooling are usually compatible as well. Nest states that their thermostats are compatible with more than 95% of existing systems.
- Currently there are four main compatibility issues: (1) ductless heat pumps, (2) variable speed heat pumps, (3) zonal electric heat, and (4) proprietary systems. The leading manufacturers indicated there are no specific plans that they are aware of aimed at resolving the existing compatibility

[3] While energy efficiency programs are not typically a supply channel, the research team includes them here because the relevant interviewees all mentioned them and energy efficiency programs represent a significant part of the market.

[4] The recalculation involved collapsing the Smart and Smart/Wi-Fi (but excluding the Wi-Fi enabled) from RBSA II Table 152.

[5] While the RBSA II data does allow the researcher to distinguish between connected and smart thermostats in general, because of large amounts of missing data, it does not provide the granularity needed to distinguish between smart and advanced smart thermostats.

issues. However, other non-OEM third party manufacturers in the market (mentioned in the detailed findings) are supplying new controls for ductless heat pumps and zonal heating.

Detailed Findings

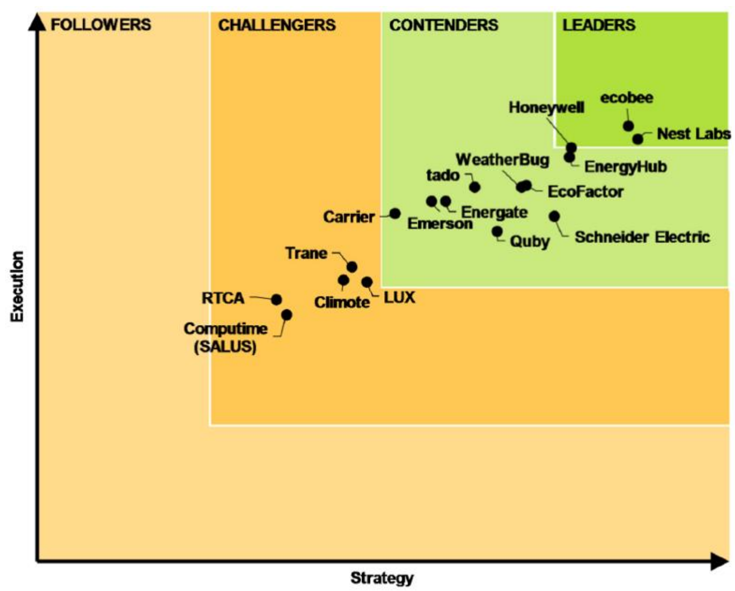
The following discussion presents detailed findings by topic area and associated research questions.

Defining the Technologies in the Market

What are all the different options in the market and what are the key features of those measures that impact energy consumption?

There are currently many manufacturers, hundreds of thermostats, and an array of software and service vendors in the global connected and smart thermostat (including advanced smart) market. Though it is slightly dated (developed in 2016) and does not include all the players in the market today, Figure 1 compares the majority of these manufacturers showing ecobee, Nest Labs and Honeywell as the industry leaders. Among the contenders are several firms offering thermostat optimization services[6] such as WeatherBug (now Whisker Labs), EnergyHub, and EcoFactor, as well as some traditional HVAC control manufacturers such as Schneider Electric, Carrier, and Emerson. The challengers are companies such as Trane and Lux.

Figure 1. Hardware, Software, and Service Vendors Operating in the Communicating and Smart Thermostat Market



Source: Navigant Research 2016

6 Thermostat optimization services are web- or cloud-based services that utilize data from the thermostats and external data, such as local temperature readings, to make slight adjustments to thermostat settings to improve performance. Thermostat optimization vendors do not typically manufacture hardware (thermostats); they are software solutions.

Not shown in the figure are also several firms that have developed controls for ductless heat pumps (which so far, are not compatible with smart thermostats). These controls are often like smart thermostats, offering mobile apps for interacting with the device and some offering proximity sensing, but none that the research team is aware of that offer on-board occupancy sensing or learning algorithms. Examples of these smart controls include:

- Cielo Breezi (https://www.cielowigle.com/)
- Tado (https://www.tado.com/us/)
- Sensibo (https://sensibo.com/)
- Momit (https://www.momit.com/en-us/).[7]

Various thermostat features can affect energy savings. Some features are more behavioral, where energy savings *can* occur if the user responds to information from the thermostat or interacts appropriately with it. Other features are non-behavioral, and more hardware related, where the thermostat itself adjusts its operation and *can* save energy accordingly. Almost all features, however, whether behavioral or non-behavioral, do not guarantee energy savings; the non-behavioral features need to be setup appropriately and users need to respond appropriately to the behavioral features to maximize potential energy savings. The key behavioral and non-behavioral thermostat features include:

Behavioral

- Online or app-based ability to interact with the thermostat
- Intuitive user interface
- Provision of feedback about energy use and HVAC runtimes
- Ability to integrate with other devices/apps such as Amazon Alexa or Apple Home Kit

Non-behavioral

- Scheduling and setbacks (assuming the user programs a schedule)
- Geofencing, on-board, and/or sensor-based occupancy sensing
- Ability to read external temperature (via sensor or weather station-based) to fine-tune thermostat operation
- The ability to read the temperature across multiple rooms to fine-tune temperature (with the use of additional sensors)
- Heat pump optimization (the ability to rely on external temperature to set coolest temperature at which auxiliary heat will go on, the ability to control compressor lock out temperatures, or the ability to do both based on outside air temperature and compressor run time).
- Algorithms that learn occupant behavior and calculate building thermal capacity and fine-tune thermostat settings accordingly

[7] Ductless heat pumps are not compatible with most smart thermostats. This topic is discussed later in the Compatibility section of this memo.

The Technology Matrix provided as a companion to this memo lists all thermostats that currently meet the ENERGY STAR Connected Thermostat Specification (ENERGY STAR 2017), along with the primary features of each thermostat.

What are the definitions or "buckets" that different thermostats can fall into that matter for the modeling work?

Defining a categorization schema for thermostats is complicated by the fact that there is no consensus across the market on definitions of smart thermostats. While line voltage, manual, and programmable units are straightforward, various organizations define categories differently for the more advanced thermostats. For example, when asked to define a "smart" thermostat, even the relatively small number of interviewees for this study provided a broad range of responses, ranging from "anything with Wi-Fi access that is demand response compatible" to thermostats with the most advanced learning algorithms.

CLEAResult (2016) puts forth that a number of key pieces of functionality distinguish smart thermostats from programmable units, including (1) Wi-Fi connectivity to support remote programming and monitoring (as well as demand response, if applicable) (2) an intuitive user interface, (3) an online dashboard that gives users remote access to their thermostat settings, (4) occupancy sensing—either on-board the device, external-to-the-device sensors, or geofencing, and (5) algorithms that learn occupant behaviors. Relying on these functionalities, CLEAResult developed a schema for categorizing thermostats (excluding manual thermostats) that includes three classes: (1) programmable, (2) connected, and (3) smart.

This research team, however, argues for two categories of smart thermostats: (1) smart thermostats, and (2) advanced smart thermostats. The key features that differentiate smart thermostats and advanced smart thermostats include the ability to sense or incorporate outdoor temperatures for heat pump optimization,[8] on-board occupancy sensing, and learning algorithms. Another requirement that needs to be met in the Northwest is that prior research needs to have shown savings. As such, to best meet BPA market modeling needs, the four classes of thermostats above manual units include: (1) programmable thermostats, (2) connected thermostats, (3) smart thermostats, and (4) advanced smart thermostats.[9] These classes and criteria that differentiate them are shown in

[8] Heat pump optimization is included because of the relatively high saturation of heat pumps in the Northwest. This feature may not be relevant to some regions, where heat pumps are uncommon.

[9] Smart ductless heat pump controls might reasonably be included in a typology (probably in the smart thermostat category), but we limit this discussion to actual thermostats.

Table 5.

Table 5. Proposed Thermostat Definitions

Category	Research Team Definition
Line Voltage	• Thermostats that are in line with and directly switch system power (120 or 240 volts) • Used with electric space heaters such as a baseboard heaters or a direct-wired electric furnaces
Manual	• Simple thermostats that regulate the HVAC system, where changes in temperature need to be made by manually adjusting the device
Programmable	• Thermostat where the occupant can set schedules and setbacks • Displays temperatures ad operating modes
Connected	• Thermostat that does everything a programmable thermostat does, but also has Wi-Fi capabilities • Most offer an online dashboard or mobile app to control the device and report usage characteristics
Smart	• Thermostat that incorporates everything a connected thermostat does, but also supports proximity sensing to indirectly detect occupants by external device (geofencing) or optional sensors that can be added to the thermostat • Basic demand response capabilities
Advanced Smart	• Thermostat that incorporates everything programmable, connected and smart thermostat have, but also has occupancy sensing directly on-board the device • Heat pump optimization • Algorithms that learn occupants' behaviors and characteristics of the structure and adjusts the device to improve scheduling and performance • Research-proven energy efficiency savings

Source: Adapted from CLEAResult, 2018

It is worth noting that no identified literature source differentiated "smart thermostats" from "advanced smart thermostats." However, when asked, several interviewees agreed that "not all smart thermostats are made equal," and that there are distinct levels of smart thermostats. The complexity of this issue is represented in the Technologies tab of the companion Technology Matrix. Some key observations include:

- The BPA Residential Smart Thermostats Qualified Product List (version 5/7/18) and the Energy Trust qualified models (website last viewed 8/30/18)[10] are the most constrained specifications and capture what this memo classes as the "advanced smart thermostats." These thermostats have all the features of programmable thermostats, connected thermostats, and smart thermostats, but also include *on-board* occupancy sensing, heat pump optimization, learning algorithms, and

[10] https://www.energytrust.org/incentives/smart-thermostats/#tab-two

maybe most importantly, research-proven energy savings. The BPA list only includes six thermostat models (Nest Learning, Nest Thermostat E, ecobee 3, ecobee 4, Carrier Cor, and Bryant Housewise) while the Energy Trust only includes four (same as BPA less the Carrier Cor and Bryant Housewise).[11]

- The Regional Technical Forum (RTF) and RBSA II smart thermostat category are the next most stringent, capturing what this memo classes as the "smart" thermostats.[12] These models have all the features of the programmable thermostats and connected thermostats, but also have geofencing or occupancy sensing from non-onboard sensors and offer basic demand response. This category includes models such as the Honeywell Lyric, Honeywell T6 Pro, and the Lux models.
- The RBSA Wi-Fi category, Puget Sound Energy, and ENERGY STAR are the least stringent specifications. As shown in the Technology Matrix, these thermostats are not really smart as they do not offer occupancy or proximity sensing, heat pump optimization, and/or learning algorithms. These thermostats are best classed as connected.
- Several options exist for how to address these differences as they relate to saturation and growth in the momentum modeling efforts, acknowledging that the RBSA II data might be the most useful:
    1. First, since the RBSA II is the most reliable source of saturation data, collapse the smart and advanced smart categories in the model and use the RBSA II numbers (or some adjusted values). This, however runs the risk of overstating saturation and momentum savings.
    2. The second option involves recategorizing RBSA II data using model numbers available in the data. However, it is worth noting that of the 58 entries for smart and smart/wi-fi thermostats, most of these of these cases (n= 48 or 83%) have "unknown" model numbers and 10 (17%) have unknown brand <u>and</u> model number. Thus, the data may not support such an approach.
    3. The third, choice would be to revise future RBSA data collection efforts, focusing on differentiating thermostat types in a more granular fashion. However, as a knowledgeable interviewee noted, it is often difficult for data collectors to differentiate thermostat types in the field without collecting model numbers.
    4. A fourth option could involve the use of manufacturer-provided sales data to estimate the things like the number of advanced smart thermostats installed and market growth rates. Of course, the coverage and granularity of the data will dictate what data gaps can be filled by sales data.

What is the priority for features that we should be paying particular attention to? (such as, "the majority of savings comes from these key features which matter most")

[11] One interviewee raised an interesting point in reference to the BPA and Energy Trust qualified product lists. They noted that only the most advanced thermostats are included in the lists–which are also the most expensive units in the market. The interviewee put forth that this presents some social equity issues as people with lower and medium income likely do not have roughly $200 to spend on a thermostat.

[12] It is worth noting that even though the RTF specification covers what we call "smart" thermostats, the savings estimates are actually based on studies that evaluated "advanced smart" thermostats.

Energy savings from an advanced smart thermostat can come from a relatively small number of mechanisms regardless of the specific features involved. These include: (1) reduced heating/cooling due to more scheduled setbacks, (2) reduced heating/cooling due to setback from occupancy detection, and (3) improved heat pump efficiency (RTF 2018). Manufacturers that offer learning algorithms argue that the algorithms also contribute notably to energy savings.

Savings from increased scheduled setbacks assumes that the new thermostat replaced a manual thermostat operated at a constant (or near constant) temperature, or that it replaced a programmable thermostat and setbacks are now more aggressive. However, numerous past studies have shown that both assumptions are not always true; thus, savings from more scheduled setbacks are not guaranteed. The main problem that has been found in past studies is a baseline issue. The issue is that many people who had a manual thermostat were making adjustments to their thermostat (such as turning it up or down based on residence occupancy), and not using the with a constant temperature setting. Giving these homes a programmable thermostat can actually increase energy use. For example, take a customer that had a manual thermostat who adjusted it daily when, say, going to work. If you give this person a programmable thermostat they will likely, like most people, program the thermostats to start heating/cooling there home *before* they are at the residence so it will be at the correct temperature when they arrive home. In this scenario, the home would experience an increase in energy use due to extended run times.

Nearly all the interviewees agreed that occupancy sensing is likely the feature most affecting energy savings. However, not all smart thermostats with occupancy detection will automatically save energy. Thermostats use three technologies for adjusting thermostats based on home occupancy: (1) on-board occupancy sensing, (2) remote sensor-based occupancy sensing, and (3) geofencing (sometimes referred to as proximity sensing). In all cases, when the thermostat detects nobody is home or using the room in which the occupancy sensor is located, it will adjust the temperature accordingly. However, these three technologies are not equal.

- On-board occupancy sensing incorporates movement sensors into the thermostat itself that detect movement in the room the thermostat is located in. This is likely the most reliable occupancy sensing as it comes incorporated into the thermostat and is typically packaged in the default mode of "on."
- Remote sensors can be bought separately for some thermostats that detect occupancy in additional rooms and adjust the home's overall temperature accordingly. However, in addition to the fact that they are optional, installation and setup complexities run the risk that these added sensors may not work correctly and may not reliably contribute to energy savings.
- Geofencing involves linking a mobile device to the thermostat via the thermostat app, which then detects home occupancy based on the location of the mobile device.[13] However, to operate correctly, geofencing also requires the user to obtain and setup the app as well as enable and setup geofencing on the app. It also poses challenges if only some occupants are set up for geofencing. For example, say your mobile phone is setup for geofencing (and you do not have on-board or sensor-based occupancy detection), but your spouse is not setup. If you leave the home but your spouse stays home, the thermostat will change based on where your phone is,

[13] These units detect occupancy at the residence level. No known device has the accuracy to detect occupancy at the room level.

unbeknownst that your spouse is home. Your spouse would need to adjust the thermostat accordingly.

Advanced smart thermostats feature on-board occupancy sensing; smart thermostats feature geofencing; either can incorporate remote sensors.

Heat pump optimization involves optimizing compressor runtimes and preventing more expensive strip heating from activating until a certain external temperature is reached. Advanced smart thermostats offer heat pump optimization.[14] For thermostats that offer it, such as the Nest Learning Thermostat, compressor runtimes are optimized by sensing the current weather and forecast to adjust how long the compressor runs to minimize the use of auxiliary heat. For example, say you have your heat pump set to warm up to 70 degrees at a certain time. The Nest thermostat will use this in conjunction with current and forecast temperatures and use the "early-on" feature to start the heat pump early to reduce the amount of time more expensive auxiliary heat might be needed to get the house up to the desired temperature at the desired time. Reductions in the need for expensive auxiliary heat can also come from setting a lower lockout temperature, or the temperature at which auxiliary heat will go on to start supplementing the heat pump's heating. This is typically set by default at about 40 degrees, but users can decrease the setting for more energy savings or increase the setting for more comfort. Heat pump optimization is an especially important feature for the Northwest given the high saturation of heat pumps.[15] Manufacturers such as Nest automatically activate this feature when the thermostat is installed with a heat pump using auxiliary heating.[16] In these instances, notable energy savings can be attained, if default settings are used.

Self-learning algorithms adjust the thermostat's operation based on factors such as the user's home profile (for example, rate of heat or cooling loss), occupant schedules, and outside weather. Typically, the algorithms include a wide range of data points and use machine learning to make micro adjustments to the thermostat settings. Unfortunately, all manufacturer algorithms are proprietary, and it is not possible to know exactly what data are collected or what adjustments are made. Additionally, the manufacturers continually improve and update the algorithms, making it virtually impossible to figure out how much energy the algorithms are saving. Nevertheless, algorithms are one of the key features that can make thermostats smart—in particular *advanced* smart thermostats—and the interviewed manufacturers assure that the learning algorithms contribute significantly to energy savings.

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[14] Some smart thermostats may also offer heat pump optimization but not all do.

[15] Heat pump optimization only applies to air source and geothermal heat pumps as smart thermostats are not generally compatible with ductless mini-split heat pumps.

[16] Actually, Nest has three heat pump settings: (1) Max Comfort, (2) Balanced, and (3) Max Savings (https://nest.com/support/article/What-is-Heat-Pump-Balance). The default, out-of-box setting is Balanced, and can be changed by the user. Nest verified that the backup heat runs approximately twice as much when the setting is not Max Savings.

Based on the literature review and the interviews conducted with market actors, it is the research team's opinion that a ranking of these four savings mechanisms by decreasing degree of potential impact on energy savings would be: (1) occupancy sensing (especially on-board occupancy sensing), (2) heat pump optimization, (3) learning algorithms, and (4) scheduled setbacks. This ranking assumes that the replaced thermostat was a programmable unit or a manual unit where the user made manual adjustments. If the replaced thermostat was a manual thermostat that was *not* being adjusted, scheduled setbacks would likely be the second greatest contributor to energy savings (occupancy sensing would still be #1 as it essentially overrides and negates any schedule).

Before departing this section, the research team also wants to discuss demand response (DR). Several of the interviewees brought up DR as one of the most important potential advantages for smart and advanced thermostats. Less an energy saving tool than a load shaping tool, many of the interviewees point to the success of DR programs across the country. A DR program does not necessarily require a smart or advanced smart thermostat as many connected thermostats can also respond to events. But, coupling DR with smart and advanced smart thermostats has the potential to both save energy and shave loads. Also, DR programs are a relatively effortless way to affect large masses of people.

Energy Savings

Which ones save energy and how much? Which ones don't save and why?

Most reports assessing energy savings from advanced smart thermostats reveal that there are energy savings, but from report to report the actual savings estimates vary widely. The research team only found two studies that resulted in *increased* energy use with the installation of a smart thermostat (this was a Honeywell Lyric in on study and an ecobee 3 with errant settings in another).[17] Appendix D summarizes the assorted studies (also incorporated into the Technology Matrix on the Bibliography tab).

Drawing conclusions about precise estimates of energy savings from the array of national studies is complicated for a couple reasons. First, there is notable variability due to *device-related issues,* which include different product feature sets, different learning algorithms, and periodic updates to device software. All these issues threaten *reliability,* or the ability to attain the same results again if the research were conducted under the same constraints, and *accuracy,* or the ability to derive the correct estimate. Second, there is notable variability due to *study-related issues* such as different climate zones, different system types, different study designs, and different methodologies for estimating energy savings. All of these issues threaten *generalizability,* or the applicability of results to the Northwest region.

The following gives some key observations related to energy savings:

- Only a few studies are applicable to the Northwest climate zone and equipment distribution (Kelsven, Weber & Urbatsch 2016; Apex Analytics 2016; Apex Analytics 2014). Of those, only two (Kelsven, Weber & Urbatsch 2016; Apex Analytics 2014) are relevant for momentum savings purposes as they focused on air source heat pumps; the other (Apex Analytics 2016) focused on gas heating. The RTF also has a measure specification for Residential Connected Thermostats.

[17] See results for the Honeywell Lyric in Apex Analytics 2016; ecobee 3 in ICF 2018.

- The two pilot studies that are most relevant to the Northwest provide rather comparable results. The first study, conducted by BPA and Franklin PUD (Kelsven, Weber & Urbatsch 2016), provided findings showing 745-955 kWh annually saved per thermostat, which was equivalent to 4% of total annual consumption and 12% of annual heating and cooling load in the evaluated homes. This compares to the first Energy Trust heat pump project (Apex Analytics 2014), which provided findings showing 781 kWh annually saved per thermostat, equating to 4.7% of total consumption and 12% of heating load in the evaluated homes. Also, the RTF Residential Connected Thermostat savings values are in-line with both regional studies.[18] Note that the connected thermostat measure is in the "planning" category due to uncertainties with the savings, and the measure has a November 30, 2019 sunset date.
- Only one study outside the region was found that included heat pumps (ICF 2018). This evaluation, conducted for the Southern Maryland Electric Cooperative (SMECO), provided results consistent with the Northwest regional studies. The SMECO study included both Nest Learning and ecobee 3 thermostats and estimated savings across both thermostats was 509 kWh annual electric savings or 2.7% of total annual consumption. However, the study authors describe initial problems associated with the ecobee thermostat heat pump settings that resulted energy use increases for these devices. When excluding the ecobee thermostats energy savings increase to 774 annual kWh saved, or 4% of total consumption – very much in-line with the regional savings estimates.
- Most of the studies have been conducted in climates cooler than the Northwest that also have hotter summers such as Maryland (ICF 2018), Colorado (Nexant 2017), Illinois (Navigant 2016), Indiana (Cadmus 2015), and Massachusetts (Cadmus 2012). Harsher climates tend to be associated with forced air furnaces coupled with central air conditioners, and the energy savings are gas heat and electric cooling. Thus, many of the results may not be entirely applicable to the distribution of HVAC equipment in much of the Northwest, limiting their value for momentum modeling purposes.
- By far, the Nest Learning Thermostat is the most common thermostat covered by the evaluations; of the 11 evaluations the research team found, Nest was included in 10 of the studies. The Nest Learning Thermostat was sometimes the only thermostat included (in four of the nine studies); it was coupled with another thermostat in the remaining six of nine studies. As such, it should be noted that almost all the evaluation studies actually provide results for advanced smart thermostats. The research team did not locate any studies that covered just smart thermostats.
- One study compared Nest to Ecofactor's Proactive Energy Efficiency Service (a software-as-a-service offering) (Herter Energy Solution 2014). The study estimated the Ecofactor service yielded twice the energy savings as the Nest (3.2% versus 1.6% of total household consumption).
- The smart thermostat/advanced smart thermostat distinction is relevant to some of the studies. Two studies presumably included the Nest Learning Thermostat (advanced), ecobee 3 (advanced), and Honeywell Lyric (smart), though it is impossible to say for sure as the studies anonymized the thermostats (Applied Energy Solutions 2018; Nexant 2017). The Energy Trust of Oregon

[18] Note that the RTF measure is in-line with the regional studies because estimates from Energy Trust evaluations were used to develop estimates for the RTF measure.

conducted one of the very few studies relying on a transparent comparative design (Apex Analytics 2016). This study found that the Nest Learning Thermostat resulted in approximately ***5% energy savings***, while the Honeywell Lyric resulted in about a ***4% increase in energy use***. The evaluators posited much of the Lyric increase to be the result of users not programming the geofencing feature, thus preventing the Lyric thermostats from adjusting to account for occupancy—one of the greatest contributors to energy savings. However, it is not clear if other aspects or features of the thermostats drove or helped drive the differences.

- ***Though there is significant variability in savings estimates across all the evaluation studies, the results of the two regional studies and RTF measure specification are quite consistent. Given this, it is the research team's position that the best resource for estimating residential advanced smart thermostat momentum savings until more data are available is the RTF savings values by system type and climate zone*** (for details, see the *Residential Connected Thermostat Workbook* (RTF 2016)). It should be noted that the savings estimates will almost certainly be updated as more studies emerge, meaning the values above should be considered placeholder values.

Why do some people use more energy when they get a smart thermostat?

Interviewees described multiple situations that could cause energy use to increase immediately after installation:

- **Advanced smart thermostat algorithms need time to learn**. The algorithms are based on machine learning and need time to collect data about user behaviors and building characteristics. For example, if a person already had an efficient schedule setup with a programmable thermostat that the new thermostat replaced, they could experience increased energy use immediately after installation during the learning period. Nest states that any increase in energy use should start to disappear after a week or so.
- **Default settings on some thermostats are not set up to maximize energy savings**. For example, geofencing may not be set up as a default feature; units that offer geofencing save energy through proximity sensing only when the user sets up the feature. One study showed that users of Nest (which has on-board occupancy sensing defaulted to on) were far more likely than users of Lyric (for which geofencing needs to be set up) to use the energy-saving occupancy detection features (Apex Analytics 2016); about 88% of Nest users left occupancy detection on; only 57% of Lyric users enabled geofencing. As another example, 2017-18 interviews with HVAC contractors as part of a different study (Folks and Malinick 2018) said that many of their customers do not enable the Wi-Fi settings on their units, with one contractor estimating that 97% of their customers do not enable the Wi-Fi connection that supports many of the smart features of the thermostat.
- **Users may change default settings that were originally setup to save energy**. For example, with a Nest thermostat and a heat pump, "Balanced" is the default setting and switching to "Max Comfort" will increase energy use (while switching to "Max Savings" will increase savings). However, one study in which Nest thermostats were installed with the "Max Savings" setting showed that relatively few people (14%) changed the setting during the study period (Apex Analytics 2014).

- **Incorrect installation can lead to increased energy use**. For example, a two-stage system wired as a one-stage system would use more energy.
- **Other idiosyncrasies with certain devices can lead to increased energy use.** Some thermostats will detect moving shadows, pets, or movement outside if located too close to a window. If a person's old thermostat was a programmable unit run with setbacks, the new smart or advanced smart thermostat can run longer because it may now erroneously detect movement and run outside of the setback periods. One researcher for the current BPA study experienced a problem with the geofencing and Smart Home/Away feature on their ecobee 3. They found that when they returned home during the day and the thermostat was programmed to be running in "Away" mode, the thermostat would switch to "Home", yet would not switch back to "Away" mode if they left again. Their monthly energy usage increased.

What is the overlap between CC&S/PTCS and thermostat savings? Are thermostat savings negated if paired with CC&S?

Commissioning, Controls, and Sizing (CC&S) and Performance Tested Comfort Systems (PTCS) are measure specifications that deal with heat pump installation, sizing, and controls. The research team reviewed both specifications to determine if any overlap existed with smart thermostat controls.

The only area of overlap the research team could determine is with control of heat pump auxiliary electric heat, which is used to provide additional heat when the heat pump is not able to handle the heating load. Unnecessary use of auxiliary heat is a major source of energy waste in heat pumps.

Both CC&S and PTCS require auxiliary heat lockout sequences to limit this waste. Smart thermostats also provide auxiliary heat lockout capabilities. This constitutes an overlap between CC&S/PTCS and smart thermostats, and smart thermostat savings may be partially negated when paired with either of these specifications.

However, there is some potential for optimization of the lockout, which some smart thermostats offer (Nest 2018). This optimization feature may mitigate some of the negated savings in this area.

Are there high-level notable issues for modeling that we should be aware of around the differences between the ENERGY STAR specification and BPA program specifications?

The BPA and ENERGY STAR specifications are very different and result in significantly different qualified products lists. The BPA specification results in a total of six qualified thermostats (Nest Learning and Nest E, ecobee 3 and ecobee 4, Bryant Housewise, and Carrier Cor), while at the time of drafting this memo, the ENERGY STAR specification resulted in 26 qualified thermostats (ENERGY STAR Connected Thermostat Qualified Products List available at: https://www.energystar.gov/productfinder/download/certified-connected-thermostats/; also see companion Technology Matrix as the tab Technologies includes the ENERGY STAR qualified models).[19]

The ENERGY STAR specification is dramatically different from the BPA specification.[20] Most notably, the ENERGY STAR specification does not address occupancy detection or heat pump optimization—the two

[19] The Technology Matrix includes fewer than 26 models to eliminate duplication.

[20] Appendix B provides the criteria for ENERGY STAR qualification.

main criteria for inclusion in the BPA list. Overall, the ENERGY STAR specification seems to describe connected thermostats, though the ENERGY STAR qualified products list does not include all connected thermostats in the market. It is closer to the RBSA approach, which includes subcategories for Wi-Fi and smart thermostats.

What do we need to be aware of from a savings perspective that we should watch out for when it comes to modeling thermostats?

Research has consistently shown that advanced smart thermostats save energy and it is virtually certain that their saturation will increase over the coming years. The research team believes it is prudent and proactive to begin building the procedures for incorporating smart thermostat savings into the momentum savings model. However, because of uncertainty, only placeholder savings estimates should be used until more reliable data surfaces. We take this position for several reasons:

- Savings estimates vary widely across national studies, while the regional research is rather consistent. As a result, we recommend using the RTF savings values by system type and climate zone for momentum savings modeling purposes (for detailed savings values, see the *Residential Connected Thermostat Workbook* (RTF 2016)). However, it is worth noting that there are only two relevant regional studies and more are certain to emerge, so any savings values should be considered placeholder values as new values may emerge over time.
- The RTF measure is in the Planning category and the RTF Research Strategy states that more research is needed.
- Most national studies are not relevant to Northwest savings because they do not cover electric heat, thus leaving out air source heat pumps, which are increasingly relevant to the Northwest due to their current (and presumed future) saturation in the region.
- Very few thermostat brands have been evaluated. Most studies only included Nest thermostats. Information on energy saving associated with any of the other advanced smart thermostat models is very sparse.
- According to RBSA II, the regional saturation of smart thermostats is about 5.6%. This agrees with the 5.3% estimate the research team found in the literature.
- More work is needed to derive more accurate regional saturation and growth numbers. The RBSA appears to be the only available source of saturation. However, this data does not discriminate enough between Wi-Fi/connected, smart, and advanced smart thermostats, which makes drawing conclusions about current saturation risky. Triangulating the RBSA data with sales and/or shipment data would help corroborate the RBSA findings.

Given the above, the question is: When will “better” data be available to support these efforts? It is the research team’s opinion that data on energy savings will improve as researchers complete more studies and publish more data. As utilities and/or organizations offer more smart thermostat programs, evaluation findings will follow. It also seems likely that studies will begin to assess the incremental savings of different features—something not yet present in the extent literature.

We encourage BPA to not disregard the data that manufacturers can provide. For example, ecobee said they are in the process of getting a nondisclosure agreement in place with BPA so they can share data. Depending on what the data contains, it could shed light on energy savings and saturation; multiple years of this data (or simply installation dates) could inform growth estimates.

Market Dynamics

What does the supply chain and decision chain each look like and what are the major channels for each?

The smart/advanced smart thermostat market is new and different from the traditional HVAC controls market. Traditionally, HVAC controls flow from manufacturers to distributors to the contractors who install the devices. In contrast, those interviewed agreed that smart thermostats reach residential customers through a number of channels, including (see Figure 2): (1) contractors and builders (via traditional distributors) (2) online retail, (3) brick-and-mortar retail, (4) energy efficiency programs, and (5) other providers such as security dealers, telecommunications and broadband service providers, etc.

Figure 2. Smart Thermostat Supply Chain

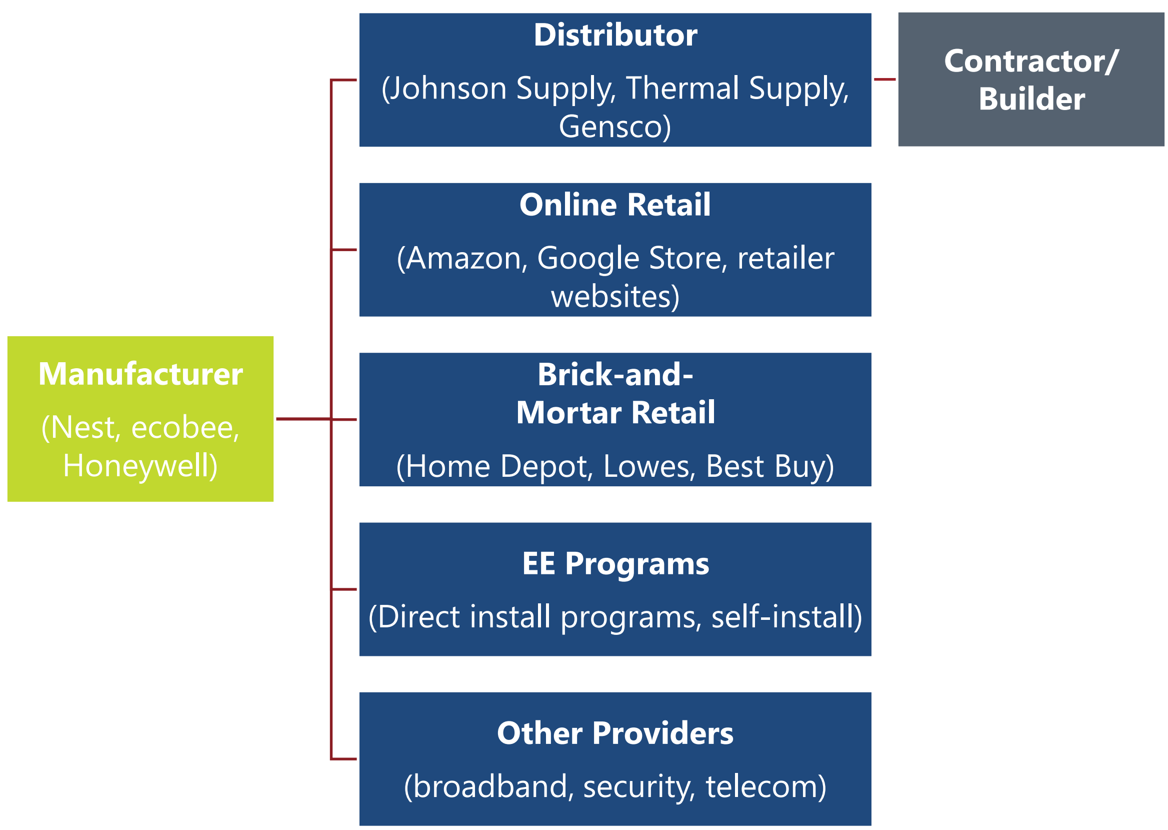
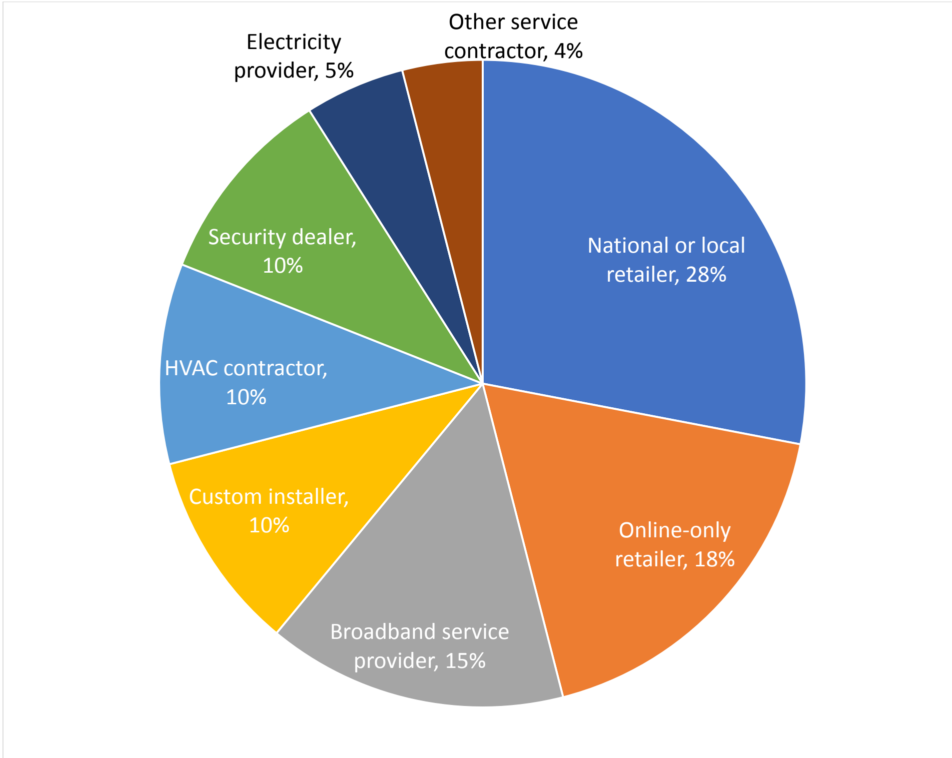


Figure 2 shows energy efficiency programs and other providers getting thermostats directly from manufacturers, which the interviewed manufacturers verified. However, according to interviewed contacts, energy efficiency programs or other service providers that are only seeking smaller quantities often go through distributors; these are captured under the Distributor channel.

Manufacturers indicated that they do not see the Northwest market operating much differently from other markets nationwide. Figure 3 shows the fragmented nature of the market by showing the relative proportion of sales flowing through each channel in 2016 nationwide.

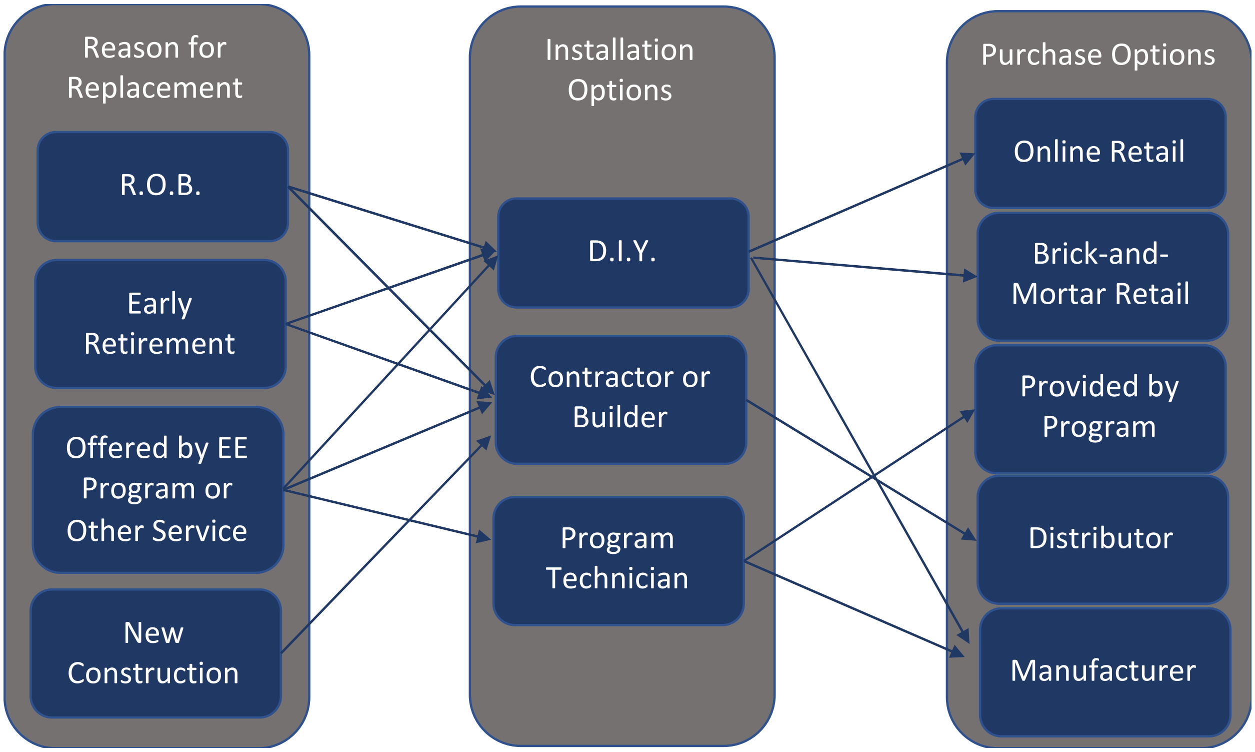
Figure 3. National Smart Thermostat Sales Channels



Source: NEEP 2016 citing Park Associates 2016

Figure 4 shows a decision chain for how advanced smart thermostat installations might occur. There are four main reasons a homeowner might install an advanced thermostat, including: (1) their old thermostat failed (replacement on burnout), (2) they wanted a newer thermostat (early retirement), (3) they were offered a new thermostat through a program or other service provider, or (4) it was a new construction. At this point the homeowner typically needs to determine whether they just want to go with the same old thermostat (or thermostat they had in their prior home), or do they want to upgrade to an advanced smart thermostat. If a new thermostat, what model do they want? Also, they need to ask themselves: Should I (or can I) install it, or should I have someone else do it for me? There are three main options for installation: (1) Do-it-yourself (DIY), (2) a contractor or builder, or (3) a program technician. Finally, the homeowner needs to decide from what source they will purchase the thermostat. With the contractor/builder pathway, this decision is made for them as the contractor/builder will obtain the thermostat from a distributor. If they pursue the DIY channel, the homeowner can obtain the thermostat through an online or brick-and-mortar retailer, directly through a manufacturer website, or from an energy efficiency program if it is self-install. If they get the thermostat through a direct install energy efficiency program or other service provider, the thermostat will come from either a manufacturer or distributor via the program technician.

Figure 4. Simplified Smart Thermostat Installation Decision Chain



How do the technologies compete with each other?

The leading smart and advanced smart thermostat manufacturers (Nest, ecobee, and Honeywell) feel they compete directly with each other. Average prices as of July 18, 2018 for their thermostats are (taken from HomeDepot.com):

- Honeywell Lyric $199
- ecobee 3 $248
- ecobee 4 $249
- Nest Learning Thermostat $249

Two of the manufacturers developed thermostats (the Nest E and the ecobee 3 lite) that target people preferring a lower price point, but still wanting a smart thermostat.[21] These thermostats compete not only with other smart thermostat brands, but also within brand (for example, the Nest E is cannibalizing some sales of the Nest Learning Thermostats). The lower price point thermostats include:

- Nest E $169
- ecobee 3 lite $169

[21] Note that while the Nest E is an advanced smart thermostat, the ecobee 3 lite is only a smart thermostat.

Competition by price, according to interviewed manufacturers, holds true for the tech-savvy shopper who has done research and knows exactly what they want. It also holds true for shoppers who may be interested in certain features or marketing messages (for example, “this model saves energy”) seen in a store display, which steers them into a smart model.

For those that are less informed or uninformed, competition is a bit different. Here the competition is *all* thermostats, not just smart models. For example, if someone needs a new thermostat and has done no research, they might walk in to a Home Depot and see up to a dozen different models of thermostats to choose from—programmable, smart and advanced smart. Interviewed manufacturers agreed that many shoppers have no real idea of what they are looking for, having never put much thought into their thermostat, and simply want a thermostat that can control temperature the way their old model could. These people may tend towards much-lower-priced programmable thermostats, some of which have Wi-Fi capabilities (but many people will never activate the Wi-Fi).

Finally, some proprietary systems have no competition. For example, the Carrier Infinity series of HVAC equipment only works with a limited number of Carrier thermostats. Some interviewees expect these proprietary systems will become more common as the market continues to mature.

What is the Northwest saturation of the different measures? What do the details of the RBSA tell us about where these units are going and what they are paired with?

RBSA II showed that roughly 7% of the region’s thermostats are connected or smart thermostats (NEEA 2018, p. 29 and Table 152). However, the 7% saturation overstates the true smart or advanced smart thermostat saturation for the region because the RBSA groups: (1) Wi-Fi, (2) Smart/Wi-Fi, and (3) Smart together when deriving the saturation value.[22,23] The research team reexamined the RBSA data and estimated about a 5.6% smart and advanced smart thermostat saturation when only including only: (1) Smart and (2) Smart/Wi-Fi, though this value still likely overstates the saturation a bit because of the inclusion of the latter group. The 5.6% estimated by the research team is quite similar to the 5.3% reported by McKinsey (2017), even though it lags the 10% estimated by the Shelton Group (CLEAResult 2018 citing Shelton Energy Pulse 2016). However, interviews with regional contractors conducted as part of a separate study (Folks and Malinick 2018) also found that about one-third of those interviewed estimated that 5% or fewer homes currently have smart thermostats. Thus, the 5.6% estimate seems reasonably accurate.

[22] One interviewee told the research team that it was often difficult for the field technician to decide exactly what type of thermostat was on the wall during data collection.

[23] While the RBSA II data does provide some ability to differentiate smart from connected (Wi-Fi) thermostats, because of large amounts of “unknown” model numbers it does not provide the granularity needed to distinguish advanced smart thermostats.

Table 6 shows the distribution of RBSA II smart and advanced smart thermostats by sub-region. Nearly one-third (32%) of units are installed in the Puget Sound area; Western Oregon comes in second at 19%. Smart thermostats are rarest in Idaho (5%) and Western Washington (7%).

Table 6. RBSA II's Distribution of Smart Thermostats by Region

Sub-Region	Count	Percentage
Eastern Oregon	7	12%
Eastern Washington	9	16%
Idaho	3	5%
Puget Sound	18	32%
Western Montana	5	9%
Western Oregon	11	19%
Western Washington	4	7%
Total	**57**	

RBSA II also showed that about 93% of smart/advanced smart thermostats are installed in single family residences; 7% in manufactured homes. Also, for cooling, these thermostats are paired with central air conditioners (54%) or air source heat pumps (46%). For heating, these thermostats are paired with forced air furnaces (54%), air source heat pumps (35%), propane furnaces (6%), electric furnaces (4%), and boilers (1%).

What does the growth trend look like in the Northwest for the different technologies? What is moving, and what's not?

The research team was unable to find publicly available literature that discussed regional market shares or growth, and unsurprisingly manufacturer interviewees were unwilling to share this strategic information. Thus, all the research team can discuss is national data.

As noted earlier, estimates suggest that between 5% and 10% of American homes have installed a smart thermostat.[24] According to one source, device shipments are expected to go from 1.3 million in 2015 to 29.1 million in 2025 (CLEAResult 2018 citing Shelton Energy Pulse 2016 Report). One interviewee referenced a Parks Associates report which states that 40% of new thermostat sales are smart or advanced smart thermostat sales, suggesting that the thermostat stock will change to smart thermostats at about half the rate at which new thermostats are installed.

Estimates of growth rates vary significantly from organization to organization. For example, Grand View Research (2016) estimated the value of the global smart thermostat market at USD 785.4 million in 2015, with a compound annual growth rate (CAGR) of 18.7% from 2016 to 2022. During this same time, other estimates of CAGR include 22.3% (Research and Markets) and 31.8% (Market and Markets)..

[24] None of the national data distinguishes advanced smart thermostats. Thus, when referring to "smart thermostats" they are really referring to smart and advanced smart thermostats.

There are several for-purchase reports that likely provide more detailed information and may provide regional growth estimates, but the cost of these reports precluded their inclusion in this memo. Some of these reports include:

- *The Market for Smart Thermostats* - Park Associates - $6,500: https://www.parksassociates.com/marketfocus/market-for-smart-home-thermostats
- *Smart Thermostat Market by Component, Network Connectivity (Wired, Wireless), Application (Residential, Office Building, Industrial Building, Educational Institutional, Retail, Hospitality, and Healthcare), and Geography - Forecast to 2020* - Markets and Markets - $5,650: https://www.marketsandmarkets.com/Market-Reports/smart-thermostat-market-266618794.html?gclid=EAIaIQobChMIlvm59YCp3AIVAkOGCh1O-w68EAAYASAAEgJ80fD_BwE
- *Smart Thermostat Market - Industry Trends, Opportunities and Forecasts to 2023* - Research and Markets - $ 3,800: https://www.researchandmarkets.com/research/gm9ljh/4_47_billion?w=4
- *Smart Thermostat Market Analysis by Technology (Wi-Fi, ZigBee, Others) And Segment Forecasts To 2022* – Grand View Research - $4,450: https://www.grandviewresearch.com/industry-analysis/smart-thermostat-market
- *Navigant Research Leaderboard Report: Smart Thermostats* – Navigant Research - $3,600: https://www.navigantresearch.com/research/navigant-research-leaderboard-report-smart-thermostats

What market data in the Northwest exists? (for example, has NEEA or anyone been collecting sales data on this, or can we get it directly from the manufacturers)

Most manufacturer representatives were unwilling to share information about market shares or sales trends in an interview format as they consider this information strategic and sensitive. The only exception was ecobee, who said they will be sharing a large amount of data with BPA after a pending nondisclosure agreement is finalized.

Other interviewees were unaware of any existing data sources that would capture the entire regional market. While it may be possible to obtain sales data from distributors, this would only capture one of the several distribution channels.

One interviewee posed a creative approach to assessing sales and trends in the region. Most, if not all, smart thermostat manufacturers have an array of data including items such as the locations of where the thermostats are installed. One approach could be to request counts of thermostats installed by region by year as a proxy for sales data. This might be a big ask. Nevertheless, researchers could estimate market-level growth rates with data from only one manufacturer (for example, ecobee), if they are comfortable with the assumption that all manufacturers have comparable sales trends.[25]

BPA and Cadeo are currently pursuing manufacturer shipment data (through nondisclosure agreements) from the major market players.

[25] Of course, model documentation would need to carefully describe the data source and extrapolation assumptions so as not to violate the non-disclosure agreement.

Compatibility

What are the compatibility issues with smart thermostats?

Smart and advanced smart thermostats are designed to work with most conventional residential HVAC systems, including forced air furnaces, central AC, and air source heat pumps. Multiple stages of heating and cooling are usually compatible as well. Nest states that their thermostats are compatible with more than 95% of existing systems. However, there are some specialized cases where thermostats are not compatible at present:

- **Ductless heat pumps**: Currently, manufacturers of ductless heat pumps have not configured their units to be compatible with smart or advanced smart thermostats, which represents a market barrier on the manufacturer side, although Carrier claims their Cor thermostats are compatible with Carrier DHPs. Additionally, smart/advanced smart thermostats are currently unable to talk to each other, which is a requirement for proper control of multi-head DHP installations (installation of multiple indoor DHP units with a common outdoor condenser). Again, this represents a market barrier that could likely be overcome if the thermostat manufacturers allocated resources and effort to the issue. Some workarounds may exist but with reduced functionality and increased expense (Zitko 2018).
- **Variable speed heat pumps**: Variable speed (inverter driven) heat pumps require specialized control sequences to operate properly. Currently, smart thermostats are unable to control these units. The market barrier here is likely the proprietary nature of the manufacturer's control sequence. There may also be limitations within the smart/advanced smart thermostat as to the complexity of control sequences the device can handle. Some manufacturers are developing workarounds to allow for smart, third party, thermostat controls (LG Electronics 2018, Turpin 2015). Some equipment manufacturers have their own, proprietary controls to handle variable speed heat pumps, but so far, none of these have emerged in the literature as smart.
- **Zonal electric heat (baseboard heaters)**: These systems generally require line voltage thermostats (usually 120 V or 240 V) and for this reason are not compatible with smart/advanced smart thermostats which require lower control voltages (usually 24 V) (Grant 2018).
- **Proprietary systems**: Some advanced proprietary systems are only compatible with thermostats designed by the system manufacturer. An example is the Carrier Infinity series equipment, which requires an Infinity series thermostat.

What has been done to measure the compatibility issue?

All the manufacturer interviewees were aware of compatibility issues but admitted there are no plans in place to address current incompatibilities. The Nest interviewees said that their thermostats are currently compatible with more than 95% of the systems in the market, and at this time they do not think the remaining 5% of the market warrants their efforts.

Are there any trends indicating compatibility issues will be resolved in the future?

It remains to be seen if the industry leaders (Nest, ecobee and Honeywell) will address current incompatibilities as they represent small proportions of the overall market. Several non-OEM companies have been developing relatively smart controls for ductless heat pumps and air conditioners, which may address that incompatibility. It is not clear what the future solution will be for variable speed pumps, though proprietary solutions may address these.

Research Opportunities

The following are some proposed research topics that will further support efforts to incorporate smart thermostat savings into the Momentum Savings Modeling efforts.

- **Research is needed to better understand growth expectations for the region.** Though market research reports do present growth of the national market, no data source we could find assesses year-to-year changes or growth for the region. Growth could be estimated from manufacturer data, but this would require participation of the manufacturers.
- **RBSA data collection efforts need to better capture accurate estimates of smart and advanced smart thermostat saturation**. The RBSA II had three categories for thermostats: (1) Wi-Fi, (2) smart, and (3) Wi-Fi/smart. The last category makes it difficult to truly know the saturation of smart thermostats in the region. And maybe more problematic is there is no clear definition of what constitutes a smart thermostat in RBSA data. Moving ahead, aligning the thermostat categories with the definitions put forth in this memo would aid momentum savings modeling efforts for smart thermostats. Because only advanced smart thermostats have proven energy savings and are the only thermostat category qualified for BPA and Energy Trust programs, a way of delineating these devices in RBSA is needed.
- **Research is needed to better understand the smart ductless heat pump controls.** None of the current models of smart or advanced smart thermostats are compatible with ductless heat pumps. However, there are a growing number of so-called "smart controls" compatible with DHPs. Given the saturation of DHPs in the region, research is needed to understand the extent to which these controls provide the functionality that aligns with BPA's definition of "smart." Also, it is not clear whether there will continue to be compatibility issues across DHPs and the new controls.
- **More research is needed on savings.** Only three studies have been conducted in the region looking at smart or advanced smart thermostats, and one of these focused on gas savings. Though the two relevant reports resulted in very similar savings estimates, this is only two studies. Further, the only thermostats that have supporting studies are the advanced smart thermostats (namely Nest and ecobee), and more research is needed that covers the smart thermostats category to assess if they result in energy savings.

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Appendix B – ENERGY STAR Connected Thermostat Eligibility Criteria[26]

1. In the absence of connectivity, a consumer shall be able to:
    a. View the room temperature
    b. View and adjust the set temperature
    c. Switch between off, heating, and cooling
2. Ability for consumers to set and modify a schedule.
3. Provision of feedback to occupants about the energy impact of their choice of settings.
4. Ability for consumers to access information relevant to their HVAC energy consumption, e.g., HVAC run time.
5. The CT product shall be capable of collecting the following data, including where noted, to the indicated resolution and accuracy:
    a. Unique thermostat ID
    b. ZIP code (installed location)
    c. Controlled HVAC equipment type to the extent it can be determined by the CT product.
    d. Daily cooling and heating equipment run times (reported to the nearest minute)
    e. Hourly auxiliary heat run time (reported to the nearest minute)
    f. Hourly emergency heat run time (reported to the nearest minute)
    g. Hourly average conditioned space temperature (reported to nearest 0.5°F)
    h. Hourly average heating and cooling set point temperatures (reported to nearest 1.0°F)
6. Static temperature accuracy ≤ ± 2.0 degrees F
7. Network standby average power consumption ≤ 3.0 W average
8. Time to enter network standby after user interaction ≤ 5.0 minutes
9. Have demand response functionality
10. Demonstrated field savings

[26] Available at: https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Program%20Requirements%20for%20Connected%20Thermostats%20Version%201.0.pdf

Appendix C – Interview Guides

Manufacturers

1. The term "smart" thermostat is being used by some market actors, especially those working in energy efficiency. Does your company use the term "smart" thermostat? If not, what term do you use? Do you have a sense of whether the industry is converging on a common definition, or it is getting worse?
2. Do you find that customers ask for certain features, or just want a "smart" unit?
3. In general, what classes of thermostats compete with each other. What thermostats do your thermostats compete with more specifically?
4. My understanding is that there are four pathways to a smart thermostat installation. (1) online retail, (2) brick-and-mortar retail, (3) contractors and builders, and (4) EE programs. Does this sound correct to you?
5. Can you share with me a very rough estimate of what proportion of products sold flow through each channel?
6. For HVAC in general, there is typically a distributor that is situated between the manufacturer and the contactors/builders. I assume that is also the case for the smart thermostats contractor/builder pathway, but how is distribution managed for the other 3 pathways?
7. Can you share with me a rough estimate the percentage sales of smart thermostats have grown this year over last? How much growth do you expect next year? Is growth similar across different regions of the US?
8. Currently there are only a handful of companies offering smart thermostats. What do you think the market will look like in the next 3-5 years in terms of the number of thermostat manufacturers offering smart thermostats (i.e., thermostats with learning capabilities)?
9. Under typical use, what features of your t-stats provide the greatest proportion of energy savings? What % of savings do you think are due to feature A? Feature B? Etc. (Probe: Try and get studies to back up claims, if they have them)
10. There are instances where customers with smart thermostats experience increased energy consumption after installation. In your opinion, what causes this? Is anyone working on feature's or other ways to prevent this from happening?
11. One phenomenon is that different generations, versions, or updates of the same t-stat perform differently. Have you tracked changes in energy consumption, with, say new software updates? As a follow up, can you provide a list of what changes have occurred with each new version or update to your t-stat(s)?
12. What do you expect the next evolution of t-stats to be? New features? (If so, what?). Better algorithms?
13. Are there any compatibility issues with your t-stats and certain system types? Are there plans for future generations or versions of your t-stats to resolve these compatibility issues?

14. Do you plan to offer products that will control zonal heating such as baseboards, wall heaters, or ductless heat pumps?
15. Do you currently offer any data products that help utilities or program administrators analyze performance data to better understand how homes use energy? If not, do you have any plans to develop something like this?
16. [Email matrix (or excerpt) to manufacturer reps ahead of time]. Ask them: Does the information we captured seem correct?

Carrier

1. Do you make thermostat data available to utilities or energy efficiency program administrators? What kind of data can you share?
2. Are you aware of any energy efficiency program evaluations of your current "smart" products? If yes, can you share those with us?

Ecobee

1. Do the ecobee thermostats utilize learning algorithms?
2. We understand that Ecobee recently changed the default settings for air source heat pumps. What prompted you to do this, and what are the criteria for making future changes to default settings?
3. What energy efficiency program evaluations involving your products are you aware of?
4. We have heard anecdotally that it can be challenging to set up multiple smart phones on the geofencing feature? Can you tell us more about this?

Honeywell

1. Is occupancy sensing a feature of any of the Honeywell models? Which ones? Is it on-board or geofencing?
2. Can non-RedLink t-stats use additional temperature sensors?
3. Do you make thermostat data available to utilities or energy efficiency program administrators? What kind of data can you share?
3. Are you aware of any energy efficiency program evaluations of your current "smart" products?

Nest

1. Are you planning on developing any direct access data tools (such as an API) to access thermostat data and settings for utilities or program administrators?
2. Do you envision anything more aggressive or customizable for energy efficiency savings than slight alterations to set points in the seasonal savings product?

Evaluators

1. How would you define a "smart" thermostat? Do you have a sense of whether the industry is converging on a common definition, or it is getting worse?
2. If you were to create a categorization or "buckets" for all possible thermostats, what would this categorization be? For example, we have manual thermostats and programmable thermostats.

How would you characterize the newer, more advanced thermostats? [Really probe smart t-stat bucket. Could this be two buckets because some are smart (e.g., connected, geofencing, DR), and some are smarter occupancy sensing, HP optimization, learning algorithms)].

3. Does the ENERGY STAR certification process result in a list of qualified products that will result in actual energy savings?
4. Would you categorize all ENERGY STAR t-stats as smart? If not smart, what are they?
5. When conducting your evaluation of [X], did you look into what t-stat features result in the most energy savings? If so, what did you find? If no, are you aware of any studies that have looked at this?

CLEAResult

1. How does your company define a “smart” thermostat? Do you have a sense of whether the industry is converging on a common definition, or it is getting worse?
2. If you were to create a categorization or “buckets” for all possible thermostats, what would this categorization be? [Really probe smart t-stat bucket. Could this be two buckets because some are smart (e.g., connected, geofencing, DR, and some are smarter on-board occupancy sensing, HP optimization, learning algorithms, etc.)].
3. Does the ENERGY STAR certification process result in a list of qualified products that will result in actual energy savings?
4. What do you think about the ENERGY STAR specification. Would you call all those t-stats smart? If not, what are they?
5. What features of smart t-stats do you think deliver the greatest proportion of energy savings?
6. What do you expect the role of smart t-stats to be in the region over the next 5 years or so?
7. What are the greatest opportunities and greatest threats for the thermostat market in the next 5 years?

NEEA

1. Have you been collecting any sales or shipment data on smart t-stats? If so, who has provided the data?
2. Where would one get the best estimates of smart t-stat market share for the region? Would this be the RBSA? Are there any other sources we should be aware of that you know of?
3. What do you expect the role of smart t-stats to be in the region over the next 5 years or so? What is NEEA hoping to do with smart t-stats, if anything?
4. What are the greatest opportunities and greatest threats for the thermostat market in the next 5 years?

Appendix D. Smart Thermostat Evaluation Studies

Title	Utility/State	Thermostat	Thermostat Type	System Type(s)	Savings Type	Savings	Baseline Condition	Methods	Sample Sizes
Nest Learning Thermostat Pilot Program Savings Assessment	BPA/Franklin PUD	Nest Learning	Advanced Smart	ASHP	Electric heating & cooling	266-1,345 kWh; 4% of total consumption; 12% of heating/cooling load	ASHP with "no advanced controls"	Billing analysis (3 models) Nest data Participant survey	176
Residential Smart Thermostats: Impact Analysis - Electric Findings	Commonwealth Edison	Nest Learning	Advanced Smart	CAC and furnace fan	Electric cooling & electric heating (furnace fan only)	Total year: 146 kWh; 1.5% of total consumption; Cooling (May-Sep): 85 kWh; 1.8% total consumption Heating (Oct-Apr) (Furnace fan only): 59 kWh	Not stated. Presumably CAC/furnace w/o smart t-stat	Regression-based paired comparison	1,887 participants and 1,791 controls
Nest Seasonal Savings Pilot	Energy Trust	Nest Learning	Advanced Smart	Not specified, but assume ASHP and FAF	Electric cooling & electric & gas heating	Summer: 4 kWh 0.4% runtime savings; Winter: gas-18 therms/ 15 kWh (presumably furnace fan savings0 electric-121 kWh 4.7% runtime savings	Nest t-stat controlling FAF/CAC	Nest randomized design Results verified through independent billing analysis Participant survey	Summer: 2,790 opt-in participants Winter: 6,716 opt-in participants
Energy Trust of Oregon Smart Thermostat Pilot Evaluation	Energy Trust	Nest Learning & Honeywell Lyric	Advanced Smart and Smart	Gas FAF	Gas heating	Nest: 34 therms; 6% of heating load Lyric: 24-29 therms INCREASE; 4-5% heating load INCREASE	Not stated. Presumably FAF w/o smart t-stat	Randomized design to test two t-tats Billing analysis Participant survey	212 Nest; 171 Lyric
SMECO Smart Thermostat Pilot	SMECO	Nest Learning, ecobee 3, and WeatherBug-optimized Emerson Sensi	Advanced Smart	FAFs w/ central air; ASHPs	Gas heating & electric cooling	Across all brands: 509 kWh; 2.7% total consumption Excluding ecobee: 774 kWh; 4% total consumption	Not stated. Presumably CAC/furnace or heat pump w/o smart t-stat	Quasi-experimental pre-post	598
Wi-Fi Programmable	Massachusetts	1st gen ecobee "Smart" -Wi-Fi	Connected	CAC and gas FAF	Electric cooling &	ecobee: gas-90 therms; 8%	Not stated. Presumably non-	Billing analysis	86 (69 in MA; 17 in RI)

Title	Utility/State	Thermostat	Thermostat Type	System Type(s)	Savings Type	Savings	Baseline Condition	Methods	Sample Sizes
Controllable Thermostat Pilot Program Evaluation		and communicating, not smart by current standards			gas heating	total consumption. Electric-104 kWh; 16% total consumption Other T-stat: gas-113 therms; 10% total	connected programmable t-stat		
SMUD's Smart Thermostat Pilot - Load Impact Evaluation	SMUD	Nest Learning and SaaS Ecofactor Proactive Energy Efficiency Service (Computime CTW218)	Advanced Smart	CAC and unspecified central heating	Electric cooling, electric & gas heating	Nest: 150 kWh; 1.6% total consumption Ecofactor: 310 kWh; 3.2% total consumption	Non-Nest or Ecofactor	Randomized control trial billing analysis across two t-stat treatments and two rate cases	700
Evaluation of the 2013–2014 Programmable and Smart Thermostat Program	Vectren	Nest Learning & Honeywell TH211 (Prog t-stat)	Advanced Smart and Connected	Presumably CAC and gas FAF	Electric cooling & gas heating	Nest: 69 Therms (12.5% of gas heating usage); 429 kWh (13.9% of gas heating usage) Honeywell: 30 Therms (5% of electric cooling usage) 332 kWh (13.2% of electric cooling usage)	Manual t-stats	Pre-post billing analysis	Control of 3,845
Xcel Energy Colorado Smart Thermostat Pilot - Evaluation Report	Xcel - CO	Presumably Nest, ecobee & Lyric	Advanced Smart and Smart	CAC and gas FAF	Electric cooling & gas heating	Vendor 1: -3.5% total consumption (INCREASE) Vendor 2: 1.0% total consumption Vendor 3: 2.4% total electric consumption; 2.5% total gas consumption	Not stated. Presumably non-smart t-stat	Pre-post billing analysis Matched control group and DiD	Sample size in report (Table 4-1) is erroneous. Table does not sum correctly.
Energy Trust of Oregon Heat Pump Control Pilot Evaluation	Energy Trust	Nest Learning	Advanced Smart	ASHP	Electric heating	781 kWh; 4.7% of total consumption; 12% heating consumption	75% prog t-stats; 25% not prog	Billing analysis Participant survey	185

Title	Utility/State	Thermostat	Thermostat Type	System Type(s)	Savings Type	Savings	Baseline Condition	Methods	Sample Sizes
PG&E Smart Thermostat Study: Second Year Findings	PG&E	Identified as "t-stat 1," "t-stat 2" & "t-stat 3"	Unsure, but presumably Advanced Smart and Smart	Presumably CAC and gas FAF	Electric cooling & gas heating	T-stat 1: yr. 1 - 217 kWh (4%) 0 Therms; yr. 2 - 44 kWh (1%) 0 Therms T-stat 2: yr. 1- 324 kWh (5%) 0 Therms; yr. 2 - 381 kWh (5%) 0 Therms T-stat 3: yr. 1 - 293 kWh (5%) 16 Therms (4%); yr. 2 - 159 kWh (2%) 17 Therms (4%)	Not stated. Presumably not one of the tested three T-stats	Randomized encouragement design w/ DiD	T-stat 1: 916 T-stat 2: 881 T-stat 3: 410