Just How Smart: A look at Energy Trust of Oregon Nest Thermostat Pilot Program

Noah Lieb, Apex Analytics LLC, Boulder, CO
Dan Rubado, Energy Trust of Oregon, Portland, OR

ABSTRACT

The Energy Trust of Oregon developed a Nest thermostat pilot study in late 2013 as an alternative to their advanced heat pump controls measure. The pilot was designed to assess how well the Nest thermostat could lockout energy-intensive backup resistance heat without the installation of an outside temperature sensor, at temperatures in which the heat pump compressor could effectively operate.

The primary goals of the pilot evaluation, which involved staff and participant surveys coupled with a billing analysis, were to determine: if installing the Nest thermostat is a viable strategy for properly controlling central electric heat pump operation in residential settings; the electricity savings associated with this control; how customers interact with the device; and customer satisfaction with the device and its control of the comfort of their homes.

This study shows that the Nest thermostat can offer considerable energy savings in homes with electric heat pumps: the annual electric savings attributable to the Nest thermostat were 781 kWh per year, representing 4.7% of total electric usage and approximately 12% of the electric heat load. There were some technical, logistical, and participant-related challenges during the pilot, but most of the issues were resolved leaving participant interest in and satisfaction with the Nest device high. The Nest thermostat, provided it can meet cost-effectiveness requirements, is an attractive and viable candidate for being rolled out to a larger audience and implemented on a larger scale for homes with heat pumps.

Introduction

The Nest pilot was implemented in the fall of 2013 through Energy Trust's Existing Homes program. Energy Trust first sought to achieve heat pump energy savings through a heat pump advanced controls measure (HPAC, which transitioned from pilot to provisional status in January 2013). HPAC relies on contractors to properly install an outdoor temperature sensor and set the thermostat to lockout energy-intensive backup resistance heat at temperatures in which the heat pump compressor can effectively operate. Unfortunately, contractor uptake of the initial HPAC measure was low even though the market size is potentially large in Oregon. Furthermore, the Northwest Energy Efficiency Alliance's 2005 analysis of heat pump performance, which served as the motivation for a heat pump control measure, showed that many residential HVAC contractors did not install proper heat pump controls or did not set them properly to switch over to backup resistance heat at the appropriate temperature.

At the time of the pilot study, the Nest thermostat was the only commercially available programmable thermostat that could lock out the resistance heat without the installation of an outside temperature sensor. Nest uses learning algorithms to optimize the compressor runtime so as to minimize the use of backup resistance heat, which is more advanced than a straight lockout temperature threshold. The Nest thermostat has a heat pump balance point setting, which controls how frequently the heating system cuts over to backup resistance heat. The balance point was initially set by the installer to "Max Savings," to minimize reliance on backup heat to achieve the target temperature and participants were asked not to change this setting. However, customers can either go online or directly adjust the device and set this control for "Max Comfort," "Balance," or "Off" and the Nest's tolerance for using the backup resistance heater changes accordingly.

There is a behavioral component to the Nest that was assessed as a component of the pilot. The behavioral component relates to the Nests' energy management features, including an ability to "learn" the occupant's schedule and a motion sensor that detects if occupants are away. Additionally, the Nest

thermostat has a dial that allows the user to interact with it similar to a manual thermostat. There are additional features that can be accessed using a smart phone-based application, or online, allowing homeowners to adjust their thermostat remotely and monitor how often their heat pump is running. Additional potential energy saving features (with description) that the Nest thermostat offers include:

- **AutoAway:** This function minimizes heating when no one is home. When the thermostat was installed, this function was turned on.
- **Early On:** This function starts heating or cooling early so the home will be at the requested temperature at the time specified. When the thermostat was installed, this function was not turned on.
- **Filter Reminders**: This function reminds the user to change their air filter based on how many hours their heating system has been running. When the thermostat was installed, this function was not turned on.
- **AutoSchedule**: This function remembers what temperatures keep the user comfortable and creates a custom schedule for their home. When the thermostat was installed, this function was not turned on.
- **Energy History**: This function allows the user to see exactly when their system was on and see a summary of their entire month's energy use
- **Nest Leaf**: The Nest "Leaf" appears when the user turns the Nest thermostat to a temperature that will save energy.

Savings estimates for Energy Trust's heat pump advanced controls measure were developed by Ecotope and estimated to be about 836 kWh per year in Climate Zone 1 (all installations occurred in Climate Zone 1). The cost of the previous heat pump advanced control measure with the outdoor temperature sensor installation was approximately $400. The cost of the Nest thermostat and installation were approximately $600 per home for the purposes of this study (approximately $250 for the Nest thermostat and another $350 for the recruitment, pilot logistics, and installation). Energy Trust selected a direct-install implementation model over an "open" contractor model in order to expedite thermostat installation prior to the start of the heating season and ensure best case scenario installations. Using a contractor approach is expected to reduce costs (both device and installation costs) to below $400. A retail incentive could significantly reduce costs but could reduce the rate of successful installations. Costs may also go down over time due to competition and technology maturation. Based on the original savings and cost assumptions above, the Nest is marginally not cost effective (the B/C ratio is .94), though the unit may be found to be cost effective in Climate Zone 1 under lower cost installation and targeted higher-savings scenarios.

The Nest thermostat has received a substantial amount of press and appears to be catching the attention of many utility program administrators. However, there are few utility-based studies available on realized energy savings, and the Team could not find any specific to heat pump-based applications. To assess the savings associated with Nest, Energy Trust attempted to recruit 200 single-family detached, site-built or manufactured homes randomly selected from a subset of Energy Trust customers who had received a home energy audit in the past (and were thus known to have the targeted heat-pump with backup resistance heating system configuration). There were a total of 1,589 customers contacted to participate in the pilot.

A comparison group comprised 299 homes (that were not contacted) that were confirmed to have not implemented any energy-saving measures in the past year but met the same conditions as the participating homes. These homes' energy usage was compared with the energy usage of the treatment group to help determine the savings associated with the Nest installation. Participation requirements for the treatment group also included the following:

- No plans for a large remodel, weatherization, or heat pump upgrade during the study period
- Existing Wi-Fi connection
- Willingness to allow Nest Labs to share thermostat settings data with Energy Trust
- Willingness to participate in a study to test a new technology

Before the installers arrived on site, CLEAResult sent out letters and placed calls to help educate the customers who had agreed to participate, explain the details (the what/why/how of the pilot study), and to ensure customer buy-in. Site visits were ultimately conducted at 222 homes, resulting in 185 thermostat installations (the Nest device and the installation were both free to participants). Thirty-seven homes were disqualified on site due to various technical issues. Eleven of the 185 thermostats installed were removed due to technical issues, and another 22 required a second visit to get them functioning properly. Therefore, out of the original 1,589 population to be recruited to participate in the pilot and serve as the treatment group in the billing analysis, there were ultimately 174 homes that had the Nest successfully installed, translating to an achieved installation rate of 11%.

CLEAResult field staff installed the thermostats starting in late Q3 of 2013. All Nest installations were completed in Q4 of 2013, so that energy usage during the 2013-2014 heating season could be evaluated in the spring of 2014. At the time of installation, the following activities also occurred:

- The heat pump balance point setting was set to "maximum savings."
- The homeowner was instructed on how to adjust the other thermostat settings.
- CLEAResult developed standardized instructions to leave behind with the homeowner.

Methodology

The primary goals of the evaluation were to determine if installing the Nest thermostat is a viable strategy for properly controlling central electric heat pump operation in residential settings, and to determine how much electricity it saves during the heating season. In addition, the evaluation effort is being used to understand how customers interact with the Nest thermostat and their level of satisfaction with the device and the resulting comfort of their homes. Ultimately, the pilot will help determine whether the Nest thermostat can achieve cost-effective electric savings from heat pumps and should be incentivized through Energy Trust's Existing Homes program.

There were three components, or primary data collection efforts, associated with this evaluation: staff interviews, participant surveys, and a billing analysis. In addition to the three primary data collection efforts, the evaluation team also leveraged 1) an existing summary report compiled by CLEAResult that detailed many of the findings associated with the implementation of the pilot and 2) actual participant usage and settings data directly from Nest Labs.

Staff Interviews: Apex Analytics developed an interview guide for program staff at Energy Trust and CLEAResult involved in the design, management, and implementation of the pilot. In April 2014, the evaluation team interviewed four CLEAResult key staff and one Energy Trust staff member. The goal was to obtain staff perspectives on selection of the participant sample, installation and setup challenges, participant attrition, logistical and communication issues, customer reactions to the device, and ideas for successful deployment of Nest to a larger population.

Participant Surveys: The evaluation team fielded two rounds of surveys to obtain feedback from participants. A core set of questions remained consistent in both surveys to gauge whether participants changed their opinions of the device during the heating season. A web-based survey was deemed the best approach because all participants had Internet access (a requirement for the Nest installation), and were assumed to have some degree of familiarity with technology due to the high-tech nature of the Nest thermostat.

The first participant survey was deployed during the mid-heating season. Participant recruitment

and actual implementation of the web survey occurred in late January 2014. This survey focused on customer motivations for participating in the pilot, installation and setup of the device, attitudes about the device, valued features of the thermostat, home comfort, use of the device, commitment to saving energy, and satisfaction with the pilot. The entire pilot participant population (at the time of recruitment N=177) was invited to take the first survey, whereas only those who completed the first survey (N=110) were selected to take the second survey.

The second participant survey was deployed at the end of the heating season. The evaluation team recruited the same participants who responded to the Round 1 survey for a second survey in May 2014. The main objective of the second survey was to identify any changes in metrics relative to those collected during the first survey. In addition, the surveys explored participant characteristics and behaviors that might be related to the amount of energy savings and which features of the device might also affect energy savings.

Billing Analysis: Energy Trust evaluation staff constructed an analysis dataset by combining participant and comparison home data from Energy Trust's project tracking database with monthly electric billing data from Energy Trust's utility database. Staff also retrieved detailed data captured at participant homes during the implementation of the pilot and information from the two participant surveys and added these to the dataset. Staff retrieved daily weather data from NOAA and matched each home matched to the nearest weather station and computed annual electricity usage for all homes that had sufficient billing data. Pre-pilot annual usage was compared between participant and comparison homes, but no significant differences were found, confirming that the two groups were comparable. Next, Nest pilot homes were removed from the analysis if they met any of the following conditions:

- Not matched to electric billing data
- Solar PV system present
- Insufficient time series of billing data
- Received an Energy Trust incentive or service during the analysis period (1/1/2012 to 5/31/2014) resulting in more than 300 kWh of annual electric savings
- Missing square-footage or year-built data
- Outlier in pre-treatment annual electric use (<1,000 kWh or >55,000 kWh)
- Large fluctuation in annual usage (year-over-year increase in usage of more than 100% or decrease of more than 50%)
- Nest thermostat removed during follow-up period (12/16/2013 to 5/31/2014)

There was some attrition during data cleaning of the final 174 homes that received and retained the Nest thermostat during the pilot period: there were ultimately 122 homes that had sufficient electric billing data and did not receive other Energy Trust incentives to be used in the analysis. After outliers were removed, 113 homes remained, leaving 64% of the participant homes to be analyzed. Of the 299 comparison homes that were initially selected, 220 had sufficient electric billing data and did not receive other Energy Trust incentives. After outliers were removed, 211 comparison homes remained, leaving 71% of the comparison group homes to be analyzed. The analysis time frame was divided into a pre-implementation period, from 1/1/2012 to 8/12/2013, and a post-implementation period, from 12/15/2013 to 5/31/2014. Billing periods varied in length but were typically about one month. Monthly electric use was divided by the number of days in each billing period to obtain the average daily usage. Average daily temperature was used to calculate the heating degree-days (HDD) and cooling degree-days (CDD) for each billing period. HDD and CDD values were divided by the number of days in each billing period to obtain average daily HDD and CDD.

To determine the energy savings attributable to the Nest thermostat, a linear mixed effects regression model was created using square footage, year built, time period, treatment group, and average daily HDD and CDD to predict average daily electricity use. The HDD and CDD base temperatures were

optimized using model fit statistics. Interaction terms were added to the model to compare the change in usage from the pre- to post-pilot period between participant and comparison homes. The resulting "difference in differences" coefficients were used to compute the weather normalized average annual electricity savings attributable to the Nest thermostat.

Findings – Staff Interviews

Program and implementation staff interviews uncovered various challenges that were encountered during the pilot. The first issue encountered was related to participant recruitment. The major barriers to recruiting were skepticism of people on the phone (concern this was a sales call or scam) and a lack of awareness of the Nest thermostat. Interestingly, CLEAResult reported that the vast majority of people did not know anything about the Nest and had never heard of a "smart or advanced thermostat." The addition of a pre-introductory recruitment letter that provided participants some background details and invited them to participate helped to address these initial issues.

The installation of the Nest offered the next set of challenges. These challenges can be grouped into the following categories: equipment eligibility, Wi-Fi router, and thermostat technical issues. There were 37 sites that were originally sampled but ultimately determined to not qualify to participate due to equipment eligibility, Wi-Fi compatibility, or other reasons, while another 11 sites had the Nest installed but required early removal of the device before the end of the pilot period[1].

Even though every participant was asked if their home was heated by a heat pump, there were some issues early on of non-qualifying systems. The most common confusion was respondents reporting that their homes were heated by heat pumps, but they actually had electric furnaces with A/C. Several sites also had multiple heat pumps providing heat to multiple zones in the home, and one home was heated by a ground-sourced heat pump. After consultation with CLEAResult technical staff, it was determined that multiple systems and ground-sourced heat pumps introduced too many variables into the study. The screening questions were updated to emphasize that only homes heated with a single ducted, air-sourced heat pump would qualify for this study.

The Nest requires wireless Internet connectivity to receive local weather information, to allow for remote access, and to log data. Because of this, CLEAResult installers connected the Nest to Wi-Fi during each installation. One of the early problems encountered by the installers was that the homeowners were unsure of their wireless network passwords. When the installers reported this issue, CLEAResult staff amended the recruitment-and-installation phone battery to emphasize the need to have the Wi-Fi password available at the time of the appointment, effectively eliminating this issue. From the participant perspective, 11% of survey respondents noted a Wi-Fi-related issue during the installation process.

The second issue identified was the prevalence of mobile Wi-Fi hotspots as the main source of Internet access in homes. These devices, typically available from phone companies, are small portable devices that create a Wi-Fi network wherever they are located. While the Nest can connect to and work with these mobile hotspots, their portability introduces the potential for the Nest to periodically lose Internet connection when the hotspot is removed from the home. Because the Nest relies on a continuous Internet connection for weather information, CLEAResult decided that homes with mobile hotspots as the only source of Internet access would not qualify for this study.

The third Internet connectivity issue was routers that were not compatible with the Nest. From conversations with Nest technical support, CLEAResult learned that the thermostat requires the router to allow devices to go into a power-saving mode while remaining connected. The thermostat needs to enter this power-save mode to allow it to stay online while trickle-charging its battery. Unfortunately some of the most popular older routers do not support this power-save mode, and thus the Nest will not connect to

[1] An additional three participants requested that the Nest be removed at the end of the pilot study. These three were included for the billing analysis since they had the Nest installed for the duration of the heating season.

them. In some cases updating router firmware can solve these issues, but in most cases the only way to install a Nest in these homes was for the homeowner to replace their router and reschedule the installation.

The final Wi-Fi/router issue was that connecting the thermostats to Wi-Fi was often difficult due to a lack of signal strength at the thermostat location. In some homes, low signal strength caused the installers difficulty in linking thermostats to the customers' Nest accounts in a timely fashion. In some instances, the thermostat would not update to the newest software version until a date and time determined by the Nest's auto-update schedule. When the installer could not connect the Nest account, a return visit was scheduled several days later to finish connecting the account.

Early on in the pilot installation phase there were some Nest thermostat technical issues that were experienced by a not-insignificant group of the participants. The first set of problems came when a number of participants reported that their Nest thermostat was reporting higher temperatures than the actual ambient temperatures they were experiencing in the homes. This was followed up by a number of revisits, which resulted in a number of thermostats being replaced. Overall, approximately 5 to 7% of the pilot study thermostat sub-bases were found to be defective, although this was only applicable to the first generation of Nest units. The pilot installations were temporarily suspended until the issue was resolved with Nest labs.

After a consultation with technical staff at Nest to understand the defective sub-base issue mentioned above, it was discovered that the sub-bases had an issue that was most prevalent in thermostats configured to heat pumps.[2] The installations were immediately stopped so that the issue could be properly resolved to avoid further installation of potentially faulty thermostats. The problem was with the field-effect transistors (FETs) used as the switches to power the HVAC relays. When these FETs fail, they fail in a partially open position, which creates the extra heat the thermostat senses. The problem in some cases provided a signal to the compressor relay but not to the indoor fan relay, which overheated some compressors and in one case caused a compressor to fail. Nest provided a number of sub-bases to the program in order to retrofit any thermostats that had an indication of a problem. Any thermostat that had a reported problem had its original sub-base replaced. Upon receiving the sub-bases the program began retrofitting problem thermostats with the new sub-bases.

With new sub-bases retrofitted into the remaining devices, the installations began again and is considered the "second" installation period. Upon the beginning of the second installation period a new problem was discovered. A number of the new sub-bases were not installing successfully. After a discussion with the same technical staff at Nest, program staff discovered that the thermostat displays needed to be updated to a newer software version to be compatible with the new sub-bases. When a new sub-base was connected to a display with pre-version 3.5 software, the sub-base was "bricked" or rendered permanently inoperable. To prevent this issue, the thermostat displays were allowed to update by installing the original sub-base, connecting the Wi-Fi, waiting for the software auto update to run, then uninstalling and reinstalling the thermostat with the new sub-base before finalizing configuration.

An additional technical issue that arose during the installation phase was related to the wiring requirements between the Nest and the heat pump equipment. The heat pump requires at least five wires for control. Some newer heat pumps now have a communicating thermostat wherein the actual controlling of the system is done by a module located where the air handler is located. Therefore these systems only have two to four wires, and the thermostat effectively just functions as a remote control. This setup requires reconnecting wires directly to the system (effectively a complete system rewire), and systems like this require considerably more time and cost for the installation.

CLEAResult staff believed that since the program received mostly early Nest models with the sub-base issue, this issue was more pronounced for the pilot than it would be for the general population. The issue was potentially compounded by the heat pump issues discussed above. Furthermore, issues tended to be more pronounced for participants' homes due to demographics, especially the older, more technically

[2] Nest staff contend that this was an unusually high failure rate and other studies and the general population of Nest users has not experience this level of failure rates.

challenged participants. The most common complaints or issues encountered by the participants were technical in nature. This was partly attributable to the elderly demographic who were challenged by issues like resetting Nest schedules, as they were unable to reprogram it.

CLEAResult staff spoke with Nest technical support staff and determined that the pilot had significantly more issues – mostly attributable to heat pumps – than typically occur with other types of heating systems (simple single-zone furnace or boiler-heated homes). The issues were also more pronounced because the pilot used the Nest as a heat pump advanced control. Nest reported that most users, with more basic single-zone furnace or boiler systems, often can complete the installation as a do-it-yourself install (no advanced HVAC skills required).

Nest technical support proved to be the most common, easiest, and reliable method for helping to resolve all of the issues mentioned above with the Nest thermostat. There were no logistical or communication issues with customers. The only issue that installers mentioned was that participant descriptions of problems were difficult to identify over the telephone. CLEAResult ultimately had to create a set of "if-this-then-that" guidelines to test if a complete replacement of a Nest unit was warranted.

According to the staff interviews, participants were very engaged and committed to saving energy. As one installer – who installed the majority of the thermostats – stated: "Participants were thrilled and genuinely happy to have the Nest installed." Probably the most telling of all indicators related to participant engagement was the high response rate for the participant surveys.

Findings – Participant Surveys

Participation in the survey was very high, with 110 out of 177 total Nest thermostat participants responding (62% response rate). For the second survey, 85 out of the 107 eligible participants responded to the survey (79% response rate). These are the highest survey response rates of any program the Apex team has ever experienced. A minority of study participants reported changing the setting of two prominent Nest thermostat features: Heat Pump Balance (8% Survey 1, 13% Survey 2, and confirmed with 14% based on actual usage and settings data from Nest Labs) and AutoAway (19% Survey 1, 20% Survey 2). Additionally, a smaller than expected portion of survey respondents stated that they adjusted the Nest thermostat by smart phone (62% Survey 1, 61% Survey 2) or online (57% Survey 1, 64% Survey 2). As will be discussed in the billing analysis below, the team was unable to directly link specific Nest features with energy savings, though it was clear from the results that those participants who tended to use the features had considerably higher savings compared to those participants who did not use any features. Furthermore, preliminary data obtained directly from Nest Labs showed that participant backup heat run times doubled when the Max Savings heat pump balance settings were changed to a different (non-Max Savings) setting.

The most cited reason for participation in the Nest thermostat study was to lower energy bills, with 88% of respondents listing it among their three reasons for participating (see Figure 1 below). The next most frequent response provided was to save energy (49%), followed by increasing the comfort of the home (45%). Participants favorite attributes of the Nest thermostat are reviewed in Figure 2 below. Energy savings was the most frequently cited attribute (45% of all second survey respondents), while the ability to control remotely (27%) and Nest's auto-learning feature (20%) were also popular aspects of the Nest thermostat. Some of the Nest thermostat features and functionality were frequently used by study participants, such as the Nest Leaf (94%), AutoSchedule (92%), Energy History (88%), and Early On (83%). Other Nest features were not: over a third of participants, in both the first- and second-round surveys, reported not adjusting the thermostat with a smart phone or online, as well as not using the filter reminder feature.

Figure 1: Primary Reasons for Participating in the Nest Pilot Study

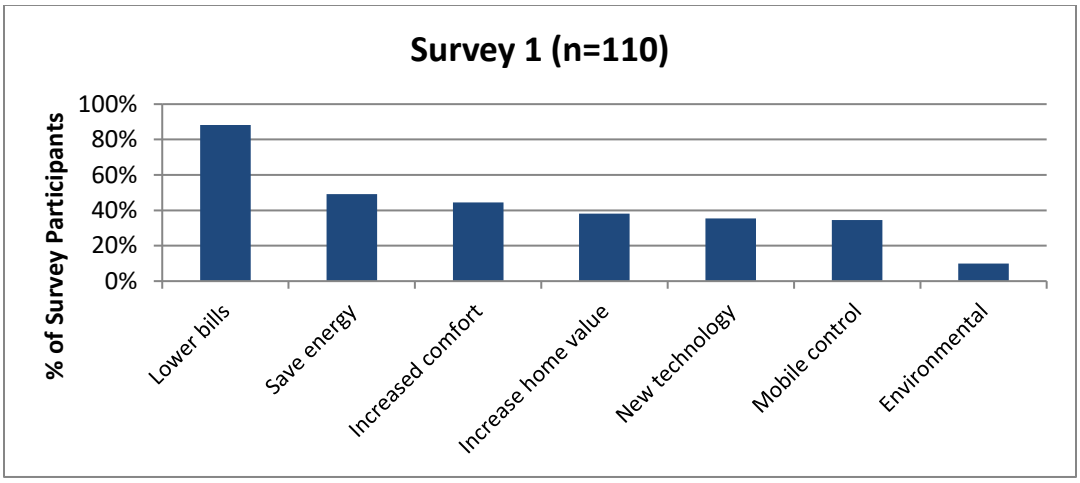
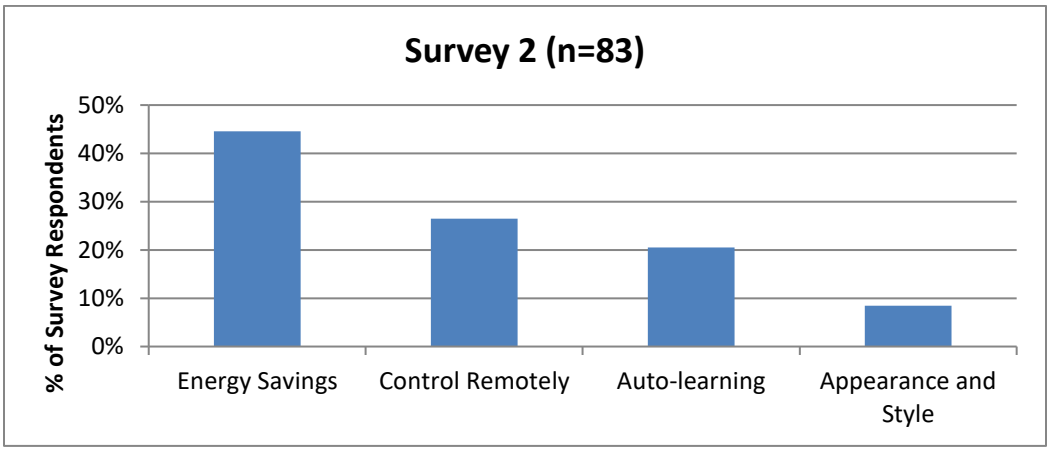


Figure 2: Participant Favorite Attributes of the Nest



In terms of the perceived usefulness of the various features, the AutoSchedule feature was perceived to be the most useful, with 81% of survey respondents in the first survey and 87% in the second survey reporting that the feature was either "Somewhat Useful" or "Very Useful." The Nest Leaf was the next most cited feature (81% first survey, 84% second survey), followed by the Energy History feature (74% first survey, 83% second survey). Some participants who responded to the survey were evidently not even aware of the features, since they added recommendations that Nest incorporate the very features that already exist.

Participants also reported increased comfort in their homes. Over 60% of survey respondents in both the first-round survey (61%) and second-round survey (66%) described the temperature of their home to be either "somewhat more comfortable" or "much more comfortable" after installing the Nest thermostat. The percentage of survey respondents who felt the temperature was either "much less comfortable" or "somewhat less comfortable" decreased from 17% to 6% between the first-round and second-round surveys. Related to this finding is the decreasing level of adjustment to settings and usage of features by study participants, with a 12% point decrease from survey one to survey two in daily interaction with the thermostat, offset by an 11% point increase over the same time frame for monthly interaction with the thermostat. Both of these findings suggest that the Nest thermostat study participants learned how to better utilize the Nest thermostat features and functionality. The findings also suggest that the Nest thermostat itself may have "learned" and become better at identifying each households' preferences and behavior.

In spite of the importance of energy savings to participants, the non-energy benefits associated with the Nest were substantial: Over 34% of all respondents believed the Nest thermostat was worth the full retail price (~$250) even if no energy savings were realized. The results suggest that study participants place a good deal of value in the Nest thermostat features, including remote access and automation. The high-level of value the participants placed on the Nest are also supported by the high satisfaction ratings the users provided, including the following:

- Over 90% of respondents rated the installation process positively (either a 4 or 5 on a five point scale.)The installation process satisfaction ratings were positive
- 79% rated their satisfaction with Nest thermostats positively (4 or 5 on five point scale), as 79% of respondents in the first survey and 89% in the second provided satisfaction ratings of either 4 or 5.

Almost half of the first-round survey respondents (41%) experienced issues after the installation process, with operational issues and Wi-Fi connection being the most frequently cited issues. At the time of the second survey, the number of survey respondents encountering issues decreased to 17%. Around half of the survey respondents experiencing issues sought assistance from either Energy Trust or Nest.

Findings – Billing Analysis

Nest pilot participants achieved significant electricity savings, at 781 kWh per year on average, representing 4.7% of annual electric usage and approximately 12% of annual heating energy use[3]. This translates to a 93% realization rate compared to the (Ecotope-based) working savings estimate of 836 kWh per year and is a relatively strong savings finding, especially given that there were many installation and technical difficulties with the Nest throughout the pilot (described above). Because this pilot study focused exclusively on electric heating savings, the analysis did not attempt to assess the additional potential savings associated with the summer cooling season.

Further analysis showed that these savings were not achieved uniformly by all participant homes in the pilot. Large differences appeared in the amount of savings realized between subgroups:

- Homes in the Portland Metro area appeared to have somewhat higher savings than those in Southern Oregon or the Willamette Valley.
- Manufactured homes appeared to have somewhat higher savings than single-family homes.
- As expected, homes with high electric usage had the highest savings, with the highest usage category achieving an impressive 1,785 kWh per year, or 11% of annual electric usage.
- Elderly participants appeared to have essentially zero savings, which is consistent with feedback and anecdotal evidence the team received during the pilot.
- The lowest income and education categories had higher savings than their more affluent and more educated counterparts. In fact, the lowest income group saved an impressive 1,654 kWh per year, on average, or 10% of total annual electric usage.
- Single-person households, which were associated with more elderly participants, appeared to experience a large increase in electric usage during the pilot. Participants with children living at home appeared to achieve slightly lower-than-average savings.

Homes where the Nest replaced a programmable thermostat were expected to save slightly less

[3] The team did not have a complete annual billing cycle to be able to pinpoint the participant-specific heating load though as a proxy the team leveraged a recent NEEA/Ecotope metering study to approximate the participant base heating load. Ecotope, April 2014; Residential Building Stock Assessment: Metering Study - http://neea.org/docs/default-source/reports/residential-building-stock-assessment--metering-study.pdf?sfvrsn=6, page 101, table 81

energy, but that was not the case. Participants who started out with a programmable thermostat saved more energy than those who did not. The Nest's other energy-saving features appeared to be relatively important to energy savings. Participants who reported keeping the AutoAway feature on, using the smart phone app to adjust their thermostat, and making use of the filter reminders all achieved somewhat higher energy savings than their counterparts. Due to sample size limitations, the team was unable to analyze the impacts of two potentially important factors that could reduce Nest thermostat savings: too few participant homes had either changed the heat pump balance point or had a prior thermostat with backup heat lockout capability to allow the Team to analyze any differences in savings associated with these factors. Fortunately, the low prevalence of these issues in the pilot homes indicates that they may not be major problems.

The Nest pilot ensured the best possible thermostat installation scenario, with site visits and ongoing support. However, there were some technical issues which may have eroded the realized energy savings in some cases. In addition, the method that was used to identify participants, including providing a free thermostat, may have resulted in many participants obtaining a Nest who would not normally have bought one. This may have created a group of participants who were mismatched to the technology and were not ideal candidates to receive a Nest, further reducing the observed savings. In the future, if the technical issues can be resolved and the thermostats find their way to customers who are better suited to them and can more effectively use them, then the average energy savings could increase.

Although the team is confident in the overall savings estimate from this analysis, a few concerns remain. Participant billing data was not based on a complete annual billing cycle but only based on post-implementation data available from January through April of 2014 at the time of the analysis. Energy Trust plans to rerun this analysis and update the savings estimates once there is a full year of follow-up data available. We have some reservations about the reliability of the results from the subgroup analyses. Each subgroup comparison began with a relatively small sample of pilot homes and cut it into even smaller pieces to analyze. With such small samples to work with and so many comparisons to explore, there may have been random fluctuations in the data that resulted in observing spurious differences. Finally, using linear mixed-effects regression models to weather-normalize utility data and estimate savings is a new technique for Energy Trust, and while the team followed recommended best practices, this method has not yet been fully vetted against our standard billing analysis methods.

Conclusions and Recommendations

The Nest pilot Study was successful on a number of key aspects: the speed of pilot launch from inception to implementation, high participant satisfaction ratings, and robust electric energy savings. The pilot did suffer some setbacks, including technical and logistical issues and found a small but vocal minority of participants who were dissatisfied with the thermostat. The quick response time, flexibility, and adaptability to resolve these issues resolved most participant frustration about the functioning of the device. This is particularly evident in the high participant satisfaction ratings. Over 90% of respondents indicated a satisfaction rating of either a 4 or 5 for the scheduling of the installation, length of time to install, and their overall rating of the installation process. Satisfaction related to the thermostat itself was also very positive, with 89% (from the second survey) providing a rating of 4 or 5. Similarly, 81% of the second survey respondents reported a 4 or 5 rating for the Nest thermostat study overall.

Staff members at both Energy Trust and CLEAResult reported that the pilot was a worthwhile and successful endeavor. The speed with which the initial pilot design was proposed and then executed was unanimously the quickest that both teams had ever experienced. All staff members interviewed felt that this pilot, if shown to provide reasonable energy savings, would be a valuable addition to the portfolio of programs offered by Energy Trust.

The Nest pilot experienced a fairly high attrition rate during the recruitment and installation process. While some challenges were unforeseeable, some issues should have been expected and

integrated as part of the pilot. The expected issues are related to successful installation of the Nest thermostats – this includes disqualified participants (due to equipment incompatibility), Wi-Fi logistical issues (lack of password, weak signal strength), hardware (defective sub-bases, wiring requirements), and participant confusion about the presence of a heat pump system. Furthermore, the participant sample was deemed to be over-representative of an elderly population (this is often termed a "sample of convenience" due to the majority of the recruitment occurring during the day), which made some of the installation and technical issues more pronounced.

The results of the billing analysis will inform the default deemed savings expected from the installation of the Nest thermostat in heat pump-heated homes in Oregon. Though some of the subgroup analysis showed significant differences and will inform future program design, the use of and reporting of the savings associated with the subgroups should be made cautiously to avoid placing too much emphasis on these findings. This is due to the lack of precision and statistical significance with some of the results. As an example, the robust savings associated with income-qualified households could be used to help target or include the Nest thermostat as part of an income-qualified program.

Every data collection resource used for this study corroborated the same finding: participants were absolutely motivated to participate due to the potential energy savings. Installation field staff indicated that this was the number one reason participants signed up, while the participant surveys were unanimously in agreement that the potential energy savings (associated with lower energy bills) was the most important attribute of the thermostat. The most cited reason for participation in the Nest thermostat study was to lower energy bills, with 88% of respondents listing it among their three reasons for participating. The next most frequent response provided was to save energy (49%), followed by increasing the comfort of the home (45%).

To best avoid recruitment and installation issues in the future, the critical breaking points of the pilot should be documented to avoid their occurrence. "Breaking points" can be viewed as distinct steps during the implementation process that could result in delays, incomplete or disqualified installations, or result in unsatisfied participants. These "breaking points" can be mapped at the onset of any pilot and can be researched using web-based queries, communicating directly with manufacturers and contractors of the measures to be installed, and reaching out to any other program administrator or utility that has offered a comparable program. In the haste to launch the pilot sufficient time and resources were not allocated to this task. As an example, the sub-base issue was well documented going back to early 2013 using a simple web-search for "Nest installation issues" or "Nest heat pump installation."

To ensure that any future recruitment reaches a broader population of households and demographics, future recruitment should occur during different times and days of the week to avoid convenience samples. To help alleviate any participant frustration with the use of the Nest device and adjustments to the settings, future programs should provide a troubleshooting guide to address the most common issues encountered during this pilot, provide a pilot contact, and ensure that support will be immediately available. As provided during this pilot, the installation process should continue to provide ample time to attempt to educate the study participants as much as possible.

Future installations should also advocate, encourage, and educate participants on the use and value of the various features. For example, by providing study participants widely available educational materials found on Nest Labs website that highlight the features and functionality of the Nest thermostat. Nest Labs dedicated web page containing detailed directions could be beneficial for participants not familiar with the technology and they should be directed to make use of it. In addition, ensure that participants are fully aware of the Nest thermostat's features and functionality from the onset and how those are likely to affect the house's temperature, comfort, and energy savings.

The prospects for an advanced thermostat capable of adaptive lockout control for heat pumps depend on participant satisfaction with the device, realized savings associated with the thermostat, and delivery approaches that reduce the installed cost of the measure. This study has shown that the Nest thermostat, when used as an alternative approach to an outdoor sensor controlling the lockout of resistance

backup heat, can offer considerable energy savings. Currently, no other advanced thermostats on the market have the combination of features Nest has that make it suitable for controlling heat pumps: using internet weather data to determine outside temperature, adaptive resistance heat lockout controls, the ability to learn how much time it takes to warm up a house under various outdoor temperatures. Therefore the Nest thermostat optimizes the use of the heat pump compressor in order to minimize the expensive resistance backup heat from running. It is this "smart algorithm" feature of the Nest that makes it so attractive for a program like this.

During this pilot study most of the technical, logistical, and participant-related challenges were resolved, leaving participant interest in and satisfaction with the Nest device high. This pilot study only tested a program direct-install method but it is possible that contractor installed or self-installed with follow-up verification could also be successful. Under the scenarios tested with this pilot, the Nest thermostat was qualified to be an attractive and viable candidate for being rolled out to a larger audience and implemented on a larger scale for heat pump heated homes.