WHITE PAPER

Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results

Nest is committed to being an industry leader in measuring and sharing energy savings results. This white paper is one in a continuing series of such empirical reports. The results reported here are averages across broad populations and are not intended as an estimate of savings that any specific user will obtain. Actual savings will vary with a number of factors including occupancy and behavior patterns, energy use, utility rates, and weather. Savings numbers are not a guarantee.

February 2015
Nest Labs

Executive Summary

This white paper summarizes the results from three studies of Nest Learning Thermostat energy savings based on comparisons of utility bills from before and after installation. Two of the studies were each independently funded, designed and evaluated -- one conducted in Oregon and the other in Indiana. The third study was performed by Nest using a national sample of Nest customers across 41 states in the U.S. who had also enrolled in Nest's MyEnergy service.

The energy savings results of all three studies were similar -- showing Nest Learning Thermostat savings equal to about 10%-12% of heating usage and electric savings equal to about 15% of cooling usage in homes with central air conditioning. Furthermore, the Oregon study noted that the majority of participants reported feeling more comfortable after the Nest Learning Thermostat was installed.

Although the average savings were similar across the three studies, it's important to note that thermostat savings in any given home can vary significantly from these averages due to differences in how people used their prior thermostat and how they use their Nest Learning Thermostat, as well as due to occupancy patterns, housing characteristics, heating and cooling equipment, and climate. Savings for any given customer may be much higher or lower than the average values. Results from future studies by Nest or third parties may also find higher or lower average savings due to differing characteristics of the populations studied.

Prior Nest analysis based on thermostat data estimated savings of up to 20% of heating use compared to the standard assumed behavior -- used by government and industry -- of maintaining a constant temperature setting all winter. The 10%-12% heating savings in this white paper are consistent with that estimate because survey results indicated that many Nest customers had previously programmed their thermostat or manually adjusted heating and cooling temperature settings. Calculations based on the survey responses suggested that Nest customers averaged about 8%-10% more efficient schedules than just maintaining a constant temperature -- implying expected additional savings in the 10%-12% range.

Nest is committed to being an industry leader in measuring and sharing energy savings results. We expect to have industry-leading measured energy savings, but we prioritize keeping people comfortable and in control of their homes. Our thermostat is designed to capture as much energy savings as feasible without compromising comfort or convenience.

Background

Programmable thermostats have been promoted as an energy savings product for many years. The real world energy savings provided by programmable thermostats has been an area of controversy. The Energy Star program of the US Environmental Protection Agency summarized the issue in 2003:

> *"Consumers are often advised that installing a programmable thermostat can save them anywhere from 10 to 30% on the space heating and cooling portion of their energy bills. While reliant on proper use of the programmable thermostat, such savings are easily true in theory; however, there needs to be more field-tested data to better substantiate savings claims. Analyses from recent field studies have suggested that programmable thermostats may be achieving considerably lower savings than their estimated potential." [EPA 2003]*

The energy savings are primarily expected to come from automatically turning down the heating set point temperature (or turning up the cooling set point) when people either aren't at home or are sleeping (known as "setback"). The magnitude of the savings depends on the how much the temperatures are changed compared to before installing the thermostat.

Field research [see Peffer et al, 2011] has found that many programmable thermostats aren't actually programmed due to usability and design problems, leading to set points that aren't much more efficient than manual thermostat set points and therefore to uncertain energy savings. This research led EPA to end the Energy Star designation for all programmable thermostats in 2009.

Still, the government and manufacturers have continued to explain the energy savings potential of well-programmed thermostats in terms of the possible savings relative to previous set point assumptions. The U.S. Department of Energy (DOE) lists heating savings of 5%-15% for a single eight hour temperature setback per day compared to a constant temperature setting [DOE 2015]. The EPA, although having ended Energy Star certification for programmable thermostats, lists savings of $180 per year for a programmable thermostat [EPA 2015]. The Nest web site states that customers "could cut 20% off your heating and cooling bill" compared to maintaining a constant temperature [Nest Labs 2015], where the constant temperature is based on customer-specific set points. Other thermostat manufacturers make a variety of savings estimates:

- "customers in the US saved an average of 23% on their heating and cooling costs" based on a comparison to an assumed 72°F constant heating set point [Ecobee 2015]
- "homeowners saved an average of 20% on their heating and cooling energy costs" based on a comparison to an assumed 72°F constant heating set point [Carrier 2014]
- "cut your heating bill by up to 31%" compared to a constant set point [Tado 2015]

All of the thermostat savings estimates are based on models of how set points affect energy use and calculate the savings compared to an assumed constant temperature set point. It's been common practice to assume a constant set point as the baseline setting behavior because it provides a clear reference condition, data on prior set points are rarely available, and because field research has found that many programmable thermostats aren't running any program [Meier et al, 2010].

The savings estimates based on the constant set point assumption are a useful guide but may not reflect actual expected savings in a specific home or average savings in a group of homes if the assumptions aren't met -- for example, if people had already been turning down the heating set point at night. Although the methods and assumptions are usually stated with the savings estimates and often include qualifiers like "save up to", it can still differ from actual consumer experience.

To assess the actual savings that customers achieved requires analyzing energy usage from before and after the thermostat installation for large groups of homes. Because such energy usage data is not usually available -- especially to thermostat manufacturers -- there have been very few such studies performed.

In May 2013, Nest acquired MyEnergy -- a company that helps customers track and analyze their utility usage and bills. The tools Nest took over from MyEnergy allow customers to gather all of their utility usage and bills in one place, providing them with the ability to monitor usage and costs month over month, year over year, and can compare performance to friends and other homes in their neighborhood. Nest also uses these insights to help analyze energy usage patterns. By comparing energy use before and after Nest Learning Thermostat installation we are able to evaluate the energy savings achieved in a sample of customers. It is this comparison, presented in a de-identified and aggregated manner, that forms the basis for this white paper. Unlike prior estimates based on assumed pre-thermostat behavior, this evaluation allows an empirical assessment of energy savings by actual consumers based on changes in their energy usage.

Methodology

Evaluating the energy savings achieved by a thermostat (or any efficiency improvement) using energy usage data might appear to be straightforward -- just calculate the difference in usage from the year before the installation to the year after the installation. But the reality is not that simple. A major challenge to evaluating energy savings is that energy usage changes from year to year for many reasons unrelated to the thermostat installation, for example:

- Weather: the winter may be colder or the summer may be milder from one year to the next, causing increased or decreased energy use. Energy savings evaluations employ statistical methods to adjust energy usage for weather variations
- Occupancy patterns: babies are born; children enter school, become teenagers, and may eventually go off to college; people get jobs, lose jobs or start or stop working from home; vacation schedules and holiday hosting vary from year to year. All of these changes can affect thermostat set points and also affect how people use their appliances, lighting, and other energy end uses.
- Home/Equipment/Appliances: people replace heating and cooling systems and appliances, build additions, add insulation, replace windows, and make other physical changes in their homes. Each of these changes can affect energy usage.

Things people do and how they live causes energy use to vary from year to year (see Figure 1 on page 8). Two main approaches are used to deal with these variations in energy use. First, energy savings studies are based on large groups of homes rather than taking results for any one home at face value. The use of larger samples allows random usage variations to average out -- with some homes increasing their energy usage due to these factors while others decrease their energy usage. Second, to account for any general trends towards increasing or decreasing energy usage (e.g. changes in energy prices, employment rates, birth rates, etc.) a control group[1] of homes not installing the thermostat is analyzed in a parallel manner to adjust the results.

In performing this energy savings analysis, we followed industry standard practices as defined by the US DOE Uniform Methods Project [DOE 2013] -- specifically, the guidelines found in "Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol" [Agnew and Goldberg 2013]. The protocol describes two primary approaches for analyzing utility energy usage data -- the "two stage" approach and the "pooled" approach.

The "two stage" approach involves analyzing the energy usage data for each customer from before and after the installation using a weather normalization procedure (a variable-base degree day regression model) and then summarizing the annualized usage and savings across homes for both the installation group and a control group of non-participant homes.

The "pooled" approach involves fitting a single linear regression model to all of the energy usage data across all homes. The model includes variables to account for degree days and variables to estimate the changes in energy use after installation (interacted with degree days). In addition, these models include customer-specific fixed effects and often include time period specific effects as well. The overall average energy savings are calculated directly from the model coefficients.

1 actually, more appropriately called a "comparison group" as the term "control group" is often reserved for only randomized experiments.

In this analysis, we employed both the “two stage” and “pooled” approaches. The analysis involved the following steps (see appendix for more details):

1. assemble and prepare the utility usage data collected through MyEnergy
2. identify Nest customers and parse energy use data into pre and post Nest Learning Thermostat installation periods
3. parse the control group (i.e., non-Nest MyEnergy customers) energy use data into comparable pre and post ”installation” periods by randomly assigning installation dates to each customer from the Nest customer sample
4. calculate heating and cooling degree days for each meter reading for each Nest customer
5. calculate weather normalized energy usage for the pre and post installation periods for each customer and fuel using variable-base degree day regression models. The electric analysis involved fitting models with and without heating and cooling terms to select the best model type for each home.
6. fit pooled time-series cross-sectional fixed effects regression models to the monthly gas and electric usage data using degree day terms and interactions and with month-specific indicator variables for the gas analysis to account for the polar vortex (an extreme cold weather system that affected the eastern half of the US in January 2014).

The electric analysis focused on homes with central air conditioning loads (defined as >500 kWh/yr in estimated cooling use) and without electric heat (there were too few electrically heated homes in the sample to reliably evaluate). The gas analysis excluded homes where electric heating usage was also detected.

A reliable savings analysis requires about a year of energy use data from before and after the installation. Due to the limited amount of historical energy usage data maintained online by most utilities and the timing of the MyEnergy acquisition and Nest customer enrollments, the vast majority of MyEnergy+Nest customers did not have sufficient pre-Nest energy use data for reliable analysis or had installed their Nest Learning Thermostats too recently to be included in the current analysis.

These data requirements led to the final sample sizes of 735 homes for the gas usage analysis and 624 homes for the electric analysis. Although these samples are large enough to estimate average overall savings, they’re not large enough to provide for more detailed analyses, especially given the heterogeneous nature of a national sample. The natural gas sample includes customers from 36 different states. California was the most common state with 15% of the sample and Illinois, Massachusetts Oregon, Texas, and Utah each represented more than 5% of the sample. The average heating season climate across these homes was moderately cold -- 4,533 heating degree days (HDD65) per year, comparable to Baltimore, MD. The electric sample included customers from 39 different states with California again being most common (19% of sample), and Texas and Massachusetts each at 10% of the sample. The electric sample homes averaged 1,729 cooling degree days (CDD65), comparable to Charlotte, North Carolina.

Findings: Gas and Electric Savings

The two energy usage analysis approaches -- pre/post and pooled -- yielded similar savings estimates (differences between approaches were not statistically significant), but the potential bias in weather normalization from the 2014 polar vortex (see more details in the appendix), led us to select the pooled approach as the best estimate of savings. The results of the analysis are summarized in Table 1.

Table 1. Gas and Electric Savings Results

		Pre-Nest Usage		Energy Savings	
Fuel	N	Total	HVAC	Total	**% of HVAC**
Natural Gas (therms/yr)	735	774	584	56 ±12	**9.6% ±2.1%**
Electricity (kWh/yr)	624	12,355	3,351	585 ±97	**17.5% ±2.9%**

Natural gas savings averaged 56 therms per year equal to 9.6% of pre-Nest heating use. Electricity savings averaged 585 kWh per year equal to 17.5% of pre-Nest HVAC[2] usage.

Most of the homes in the analysis had just a single Nest Learning Thermostat, but 19% of the gas analysis homes and 25% of the electric analysis homes had two or more Nest Learning Thermostats. We ran the analysis for just the homes with a single thermostat and found average savings of 11.0% for gas heating (60 th/yr out of 547 th heating use) and 15.5% of electric HVAC (448 kWh out of 2,897 HVAC use). The differences between these values and the overall values in the table are not statistically significant.

We calculated the estimated value of the energy savings using two approaches. In the first approach, we applied the most recent (October 2014) average U.S. residential electric and natural gas prices of 12.6¢/kwh and $13.15/mcf ($1.28/therm), as reported by the EIA [EIA 2014a], to the average therm and kWh savings, which yields $145 in annual savings. In the second approach, we applied the percent heating and cooling savings to the most recent average annual U.S. heating and cooling costs according [EIA 2014b, EIA 2015]. This calculation estimates the annual savings at $131 (9.6% of $988 for heating and 15% of $240 for cooling). The two approaches provide similar estimates. Of course both of these figures are just rough estimates of savings because energy prices vary between energy providers and change over time and marginal costs may differ from average costs. In addition, these savings are estimates for homes that have gas heating and also use central air conditioning and have average energy use consistent with the values found here. Dollar savings vary with energy savings as well as with fuel type and local energy costs.

Energy Usage and Savings Variability

Figure 1 shows the distribution of percent natural gas "savings" for the comparison group of homes that did not install Nest Learning Thermostats. This distribution is approximately symmetric around zero (no change in usage) and also shows a wide range of usage changes -- 34% of the homes experienced a change in weather normalized total natural gas use of more than 10% from year to year.

2 Although we screened out homes that were electrically heated, most homes have some winter seasonal electricity usage -- some of which is related to furnace fan power draw. To account for the savings and usage not related to cooling we expressed electric savings as a percent of HVAC use.

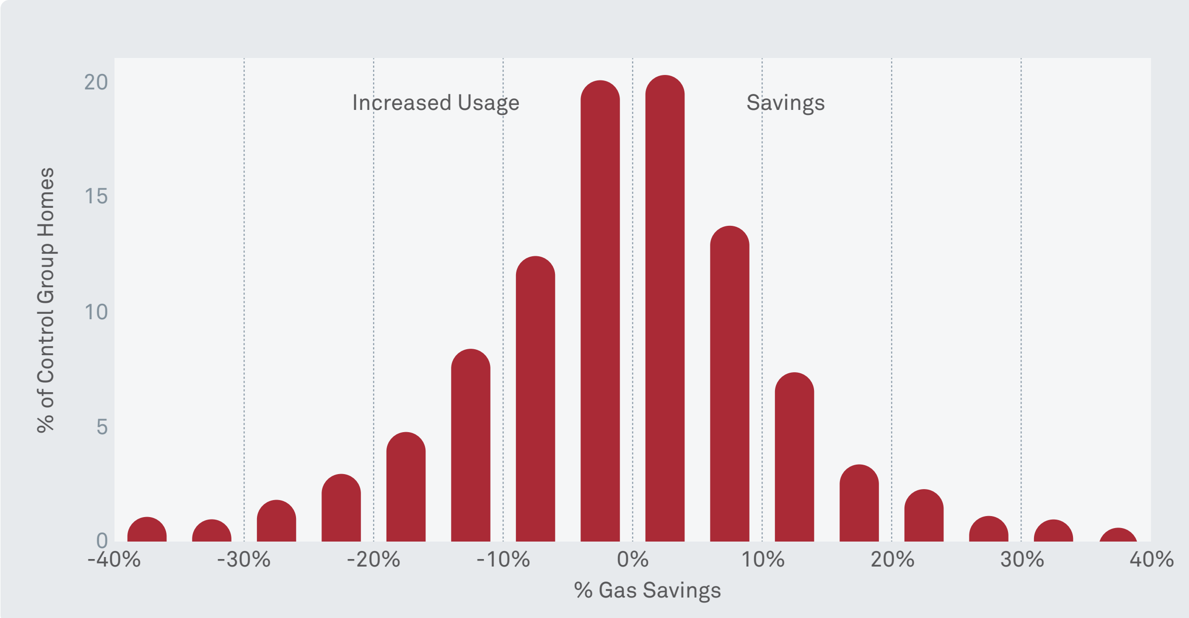

Figure 1. Distribution of Natural Gas "Savings" for non-Nest comparison group

Figure 2 shows the same graph for the Nest customers in the analysis. The peak is clearly to the right of the 0% vertical line -- indicating savings, but there's a lot of variability - including many homes where the gas usage seemed to increase.

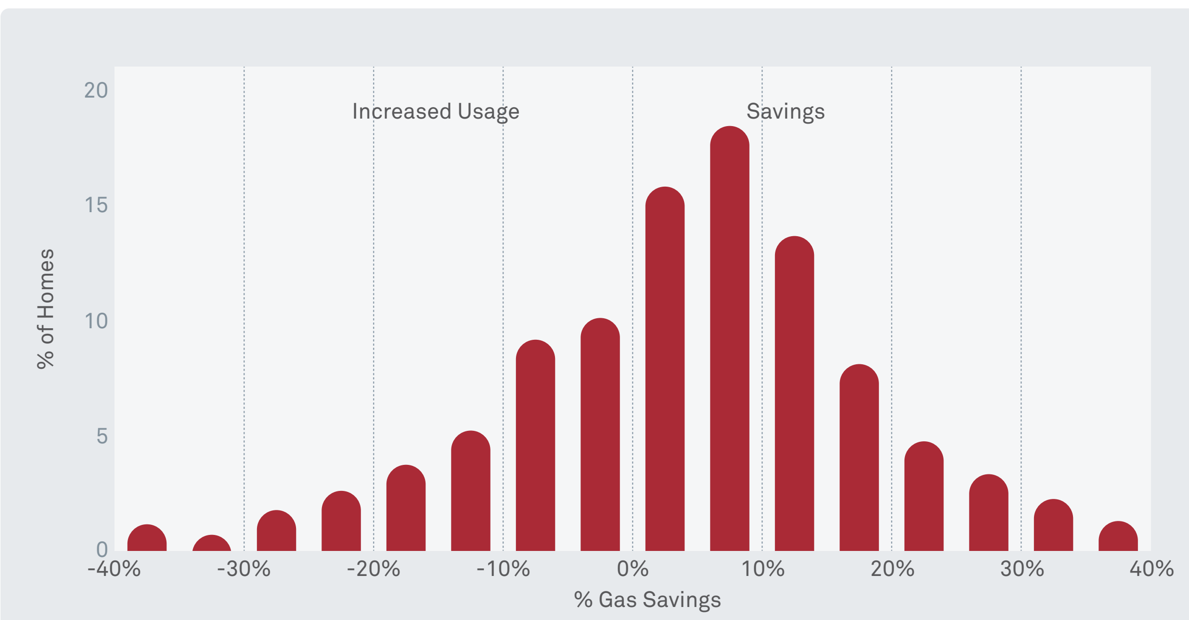

Figure 2. Distribution of Natural Gas Savings for Nest MyEnergy customers

These graphs illustrate that the change in energy use for a given home after installing a Nest Learning Thermostat (or making any other change) is not just the energy savings from the Nest Learning Thermostat but is the total change in energy usage from everything that happened over the period -- including all other changes in people's homes and how they use them. The true energy savings attributable to the thermostat is the difference between the actual energy use with the Nest Learning

Thermostat and the energy use a customer *would have had* if they hadn't installed the Nest Learning Thermostat. But what we can actually observe in people's bills is the change in usage from the year before to the year after, which includes a host of factors unrelated to the Nest Learning Thermostat.

If a thermostat saved every customer exactly 10% of their total gas usage then the savings in Figure 2 would look just like Figure 1 above, except shifted over by 10%. We would still see homes that increased their energy usage while we would see other homes with larger decreases in usage.

While Nest would love to be able to take credit for all of the energy savings when a customer's usage drops by 40% we know that there's a good chance that other things changed in their home or how they use it that may be responsible for some of that savings. Similarly, when the energy use of some customers stays the same or increases, the blame could be due to many other things that changed over time.

Thus, the actual savings we ascribe to Nest is, in essence, the difference between the results of Figure 1 (i.e., the natural year-to-year variability of energy usage) and the results of Figure 2 (i.e., the year-to-year variability of energy usage in homes installing a Nest Learning Thermostat).

Assessment of Potential Bias: Evaluating MyEnergy Customers

Like most evaluations of energy efficiency upgrades, this study is not a designed experiment or randomized control trial but is instead an "observational study". Observational studies need to consider potential sources of bias since the participants may not represent the larger population of customers or the comparison group may differ from the participants. In addition, extraneous factors such as extreme weather or energy price changes may have affected energy use in ways that differ between groups or aren't otherwise accounted for properly in the analysis.

In this study, the analysis group comprises people who purchased a Nest Learning Thermostat and also chose to sign up for MyEnergy. People who enroll in MyEnergy are interested in tracking their energy use and so they tend to be more energy conscious and efficient than the average Nest customer. Although it may seem counterintuitive, this greater interest in energy efficiency may lead to lower energy savings from a Nest Learning Thermostat. The most energy conscious customers are the ones more likely to have had efficient thermostat settings -- either because they put in the effort to properly use their old programmable thermostat or they consistently set back temperatures whenever feasible prior to having a Nest. The prior behavior has a large impact on savings potential.

We explored the potential bias from the sample composition through an email survey and an analysis of Nest settings. Table 2 summarizes some key findings from the survey.

Table 2. MyEnergy Customers compared to average Nest customers

	MyEnergy	Other Nest	Difference
Customer Survey Findings			
Had Programmable Thermostat	74%	65%	+9%
Most Efficient: Programmable with double setback	37%	28%	+9%
Least Efficient: No Regular Setback	26%	36%	-10%

Nest Device Settings			
Average Heating Set Point	66.2°F	67.2°F	-1.0°F
Average Night Setback	4.9°F	4.0°F	+0.84°F

note: Survey results are based on 657 MyEnergy and 763 other Nest customers.

The table shows that the MyEnergy customers reported having more efficient set points prior to installing the Nest than the average Nest customer surveyed. Compared to the other Nest customers, MyEnergy customers were more likely to have a programmable thermostat, more likely to employ two or more setbacks per day, and less likely to have practiced no setbacks prior to having the Nest. These differences all suggest that MyEnergy Nest customers have less potential for saving energy since they were already more efficient. We assessed the magnitude of this effect using energy modeling and estimate that the MyEnergy customers have about 2% lower savings potential than the average Nest customer -- their set points were calculated to be about 10% more efficient than a constant baseline compared to about 8% more efficient for the average Nest customer.

The last two rows of the table summarize the actual Nest Learning Thermostat customer set points during February and March 2014 for the survey homes. The MyEnergy Nest customers maintained a lower average heating set point than the average Nest customer and also had greater night temperature setbacks (primarily more frequent rather than deeper). Differences were also found for other settings, such as daytime setbacks, and for the use of Nest features such as Heat Pump Balance (more than twice as likely to select "Max Savings"). We used energy modeling to estimate the impact of these differences and calculated that the MyEnergy customers were about 2% more efficient with their Nest set points than the average Nest customer.

Based on this analysis, it appears that the MyEnergy customers were more efficient than the average Nest customer both before and after installing their Nest and the magnitude of these differences was about the same -- implying no significant bias between the groups.

It's also worth noting that both groups of Nest customers reported more efficient prior thermostat practices compared to studies of typical US household thermostat use. A literature review [Peffer et al, 2011] reported that 42% of US households had programmable thermostats in 2008 and 47% of programmable thermostats were running a program. In contrast, 65% of non-MyEnergy Nest customers reported having a programmable thermostat and 71% of those were running a program. These results indicate that Nest customers tended to have more efficient set points than the average U.S. household, which reduced the potential for savings.

Another potential source of bias is the comparison group. The comparison group of non-participants comprises people who signed up for MyEnergy on their own. The fact that they chose to enroll on their own implies that they may differ from the MyEnergy customers that were recruited by Nest. This difference could introduce a downward bias on savings if, for example, the non-Nest MyEnergy customers were more likely to pursue other efficiency upgrades on their own -- which may have led them to sign up for MyEnergy.

Overall, our analysis did not uncover any evidence of a large bias from having the study focus on MyEnergy customers, although the comparison group issue suggests any likely bias would lead toward finding lower energy savings than the average Nest customer might achieve.

Other Recent Studies of Nest Learning Thermostat Savings

Two studies have been released recently by independent third parties that evaluated the energy savings from Nest Learning Thermostat installations -- one in Oregon and one in Indiana.

Energy Trust of Oregon Heat Pump Pilot

The Oregon study [Apex Analytics, 2014] was a pilot project designed, funded, and overseen by the non-profit Energy Trust of Oregon. In the fall of 2013, the Energy Trust had a contractor install Nest Learning Thermostats in 185 homes heated by heat pumps. The Energy Trust hired an independent firm to analyze changes in energy bills and also survey participants about their experiences. The main findings from the energy billing data analysis and final customer survey included:

- customers experienced an average 12% reduction in electric heating use (781 kWh/year per home) relative to their pre-Nest usage
- 89% of customers were satisfied with their Nest Learning Thermostat
- 66% of participants reported feeling more comfortable after the Nest Learning Thermostat was installed
- 34% of participants reported that they thought the Nest Learning Thermostat was worth the full retail price even if it had provided no energy savings at all

The report cited the Nest Learning Thermostat's unique "Heat Pump Balance" feature as a key element in providing the savings. The 12% heating savings for heat pumps in Oregon is especially noteworthy given that programmable thermostats are typically not recommended for heat pumps.

The US DOE web page on thermostats (http://energy.gov/energysaver/articles/thermostats accessed 21-Jan-2015) notes:

> *"Programmable thermostats are generally not recommended for heat pumps... when a heat pump is in its heating mode, setting back its thermostat can cause the unit to operate inefficiently, thereby canceling out any savings achieved by lowering the temperature setting"*

But it goes on to note that "some companies have begun selling specially designed programmable thermostats for heat pumps, which make setting back the thermostat cost-effective". The study suggests that the Nest Learning Thermostat algorithms have succeeded in this challenge of achieving savings from setback for heat pumps.

The study findings about high customer satisfaction and improved comfort listed above are particularly noteworthy. Given the importance of behavior in energy savings from thermostats, user satisfaction with the technology and their feeling that their energy savings have not come at the expense of comfort mean that the Nest Learning Thermostat can serve its dual role as a comfort control device and an energy control device without putting those objectives in conflict. This has not always been the case with new energy-saving technologies, which can become ineffective if they force users to choose between comfort and efficiency.

Indiana Utility Pilot

The Indiana study [Aarish et al, 2015] was a pilot project designed to assess the energy savings of Nest Learning Thermostats. The project was designed, funded, and overseen by Vectren Energy, a gas and electric utility in Indiana. In the fall of 2013, Vectren hired a contractor to install Nest Learning Thermostats in 300 homes and standard programmable thermostats (Honeywell TH211 Pro 2000 series) in 300 homes. Vectren hired the Cadmus Group to perform the evaluation. The main findings from the evaluation included:

- Homes that received a Nest Learning Thermostat had average natural gas savings of 69 therms/year, equal to 12.5% (±1.5%) of the heating use
- Nest homes had average electricity savings of 429 kWh/yr, equal to 13.9% (±5%) of cooling use
- Homes that received a standard programmable thermostat averaged savings of 30 therms/yr equal to 5.0% (±1.3%) of heating use. In terms of electricity usage, they saved 332 kWh/yr equal to 13.1% (±6%) of cooling use

The Nest customers saved more than twice as much heating energy as the standard programmable thermostat customers and this difference was statistically significant. The electricity savings estimates had much larger uncertainty than the gas results and pre-existing differences in cooling use and occupancy between the groups makes it hard to draw any firm conclusions about the difference in cooling savings.

There were two aspects of the pilot that may have affected the savings comparison:

- The pilot offered thermostats for free and the resulting sample of customers were much less likely to install and use the Nest phone or tablet apps or connect to WiFi than typical Nest customers -- potentially lowering the savings from Nest Learning Thermostat features.
- Both types of thermostats were professionally installed and set up by a contractor. One of the key features of the Nest Learning Thermostat compared to standard thermostats is the ease of creating a program through the learning feature. The pilot design created a best case scenario for a standard programmable thermostat in terms of being programmed.

Furthermore, thermostat research has found that many standard programmable thermostats eventually end up with no program or set to “hold” and the Indiana study found some evidence of this behavior already. The study reported that “only 37% of participants appear to have relied on their thermostat program by the end of the study period”. Therefore, savings from a standard programmable thermostat could be expected to degrade over time as more users override their schedules.

Real World Thermostat Energy Savings

The results from the MyEnergy customer analysis and the two independent studies suggest that Nest customers are saving about 10%-12% of heating use. Although these savings are less than the 20% projected by Nest from energy modeling, the results are consistent once the different baseline behaviors are taken into account. The 20% projection was based on the standard assumption of a constant temperature setting without the Nest Learning Thermostat, but the email survey found that Nest customers reported having set points that were about 8%-10% more efficient than the constant baseline (and also more efficient than the average U.S. home). Therefore, the 10%-12% heating savings are in fact consistent with the 20% projection when adjusted for the more efficient baseline. This suggests that the modeling itself was accurate and the baseline assumption is responsible for the difference in savings.

The MyEnergy and Indiana studies found electric savings in homes with central air conditioning (and not electric heat) of about 15% of cooling use. Due to the inherently greater variability a electric use, these savings have greater uncertainty than the gas savings and larger samples and more studies would help to draw stronger conclusions about the impacts.

The real energy savings achieved from installing a Nest Learning Thermostat is expected to vary based on many factors. Table 3 lists some of the behaviors and characteristics associated with higher or lower heating savings potential from installing a Nest Learning Thermostat. A similar list would apply to cooling savings.

Table 3. Factors Associated with Higher or Lower Thermostat Savings

Larger Savings Potential	Behavior / Characteristic	Smaller Savings Potential
Rarely or never used setback, but willing to	Nighttime setback: before installing Nest	Always used setback
Often away during the day but didn't use setback	Daytime occupancy / prior setback	Home during the day or already used setback regularly
Often go away for days or weekends or vacations and forget to turn down heat; vacation homes	Vacations and other away periods	Never go away or always remember to turn down heat when away
Keep nest features enabled: auto-schedule, auto-away; set heat pump balance to max savings	Nest settings	Disable energy saving features; select less efficient settings (heat pump balance max comfort)
Colder climates (but % savings may be less)	Climate	Milder climates (but % savings may be greater)
Heat pumps with typical or excess auxiliary heat use	HVAC type	Heat pumps with little auxiliary heat use, heat pumps due to limits on setbacks from aux. Heat requirements; condensing boilers if often running in condensing mode
Leakier, less insulated homes lose heat faster during setback, save more	Building shell efficiency	Tighter, better insulated homes lose heat slowly and save less from setback
Low mass homes cool down more quickly and save more from setback	Building mass	High mass homes (e.g., Masonry) cool down more slowly and save less from setback

The dominant factor affecting energy savings will often be the efficiency of the prior schedule / set points combined with the Nest Learning Thermostat's ability to create a more efficient schedule.

Higher energy savings would be expected for a customer who would like to have night and day setbacks but can't figure out (or doesn't want to bother to figure out) how to do it automatically with his or her current thermostat and can't remember or be bothered with manually adjusting the thermostat multiple times each day.

Lower energy savings would be expected for a customer who already sets back the temperature every night and day and always remembers to turn down the heat when leaving for an extended period. Such households are already operating their HVAC efficiently and provide less opportunity for savings, but they may still want a Nest Learning Thermostat for the convenience, functionality, and design in addition to the energy savings from other Nest features.

Conclusions

This white paper has presented results from three studies of Nest Learning Thermostat energy savings based on comparisons of energy bills from before and after installation of a Nest Learning Thermostat. The results of the studies were generally similar -- showing Nest Learning Thermostat heating savings of about 10%-12% and electric savings of about 15% of cooling use in homes with central air conditioning. Although the average savings were similar across the three studies, savings can be expected to vary significantly between homes due to variations in how people set their temperatures before installing the Nest Learning Thermostat as well as due to occupancy patterns, house characteristics, and climate. Future studies by Nest or other third parties may find higher or lower average savings due to differing characteristics of the populations studied. Nest is committed to being an industry leader in measuring and sharing energy savings results. We will continue to highlight new results as they become available.

At Nest, we expect to achieve industry-leading measured energy savings, but we prioritize keeping people comfortable and in control of their homes. If we didn't care about our customers' comfort, we could probably achieve greater energy savings, but we would have failed in our primary mission. Instead, we designed our thermostat to capture as much energy savings as feasible without compromising our customers' comfort or convenience.

References

Aarish, C., M. Perussi, A. Rietz, and D. Korn. *Evaluation of the 2013–2014 Programmable and Smart Thermostat Program.* Prepared by Cadmus for Vectren Corporation. 2015.

Agnew, K. and M. Goldberg, "Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol", National Renewable Energy Laboratory report NREL/SR-7A30-53827 April 2013. accessed from http://energy.gov/sites/prod/files/2013/11/f5/53827-8.pdf

Apex Analytics LLC, "Energy Trust of Oregon Nest Learning Thermostat Heat Pump Control Pilot Evaluation", October 10, 2014 accessed from http://energytrust.org/library/reports/Nest_Pilot_Study_Evaluation_wSR.pdf

Carrier Corp. "TP--WEM01 Performance™ Series AC/HP Wi--Fi Thermostat Carrier Côr™ Thermostat" from http://dms.hvacpartners.com/docs/1009/public/02/tp-wem-01pd.pdf

Ecobee, 2015. https://www.ecobee.com/savings/

Fels, M. "PRISM: An Introduction", Energy and Buildings 9, #1-2, pp. 5-18, 1986.

Meier, A., C. Aragon, B. Hurwitz, D. Mujumdar, D. Perry, T. Peffer, M. Pritoni, "How People Actually Use Thermostats", in Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 2010. accessed from https://www.aceee.org/files/proceedings/2010/data/papers/1963.pdf

Nest Labs, 2015. https://nest.com/thermostat/saving-energy

Peffer, T., M. Pritoni, A. Meier, C. Aragon, D. Perry, "How people use thermostats in homes: A review", Building and Environment 46 (2011) 2529-2541.

Tado, 2015. https://www.tado.com/gb/heatingcontrol-savings

U.S. Department of Energy (DOE), "Uniform Methods Project For Determining Energy Efficiency Program Savings", 2013. at http://energy.gov/eere/about-us/initiatives-and-projects/uniform-methods-project-determining-energy-efficiency-progr-0

U.S. DOE 2015 http://energy.gov/energysaver/articles/thermostats

U.S. Energy Information Administration (EIA) October 2014 residential energy prices, 2014a accessed from http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a and http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_m.htm

U.S. EIA "Short-Term Energy Outlook - January 2015" see "Table WF01. Average Consumer Prices and Expenditures for Heating Fuels During the Winter", January 2015. accessed from http://www.eia.gov/forecasts/steo/tables/pdf/wf-table.pdf

U.S. EIA, "Annual Energy Outlook 2014, early release" on-line query table "Residential Key Indicators and Consumption" 2014b accessed at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014ER&subject=0-AEO2014ER&table=4-AEO2014ER&region=0-0&cases=full2013-d102312a,ref2014er-d102413a cooling energy costs calculated based on unit conversion to kWh and average price per kWh (from EIA 2014a).

U.S. Environmental Protection Agency (EPA) "Summary of Research Findings From the Programmable Thermostat Market", 2003 accessed from http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/thermostats/Summary.pdf

U.S. EPA 2015 http://www.energystar.gov/index.cfm?c=heat_cool.pr_hvac