Supplemental Data for California Smart Thermostat Work Paper

Large scale analysis of the efficiency of Nest customer thermostat set point schedules with projected heating and cooling savings compared to baseline behavior using pooled Fixed Regression Model and Comfort Temperature Analysis

Prepared by: Nest Labs, Inc.
June, 2016
Authors: Michael Blasnik, Aaron Berndt, Jeff Gleeson
Contact: jgleeson@nestlabs.com

1.0 Overview

The analysis of actual thermostat settings, combined with pooled fixed regression modeling, described in this paper provides estimates of energy savings from Nest Learning Thermostats installed in California's unique climate zones, which are widely understood to be generally milder than most regions in the United States. For a broader assessment of Nest's energy savings based on pre/post billing data analysis across the United States, please see the white paper "Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results," released by Nest in February, 2015.[1]

The results of the analysis herein demonstrates that, even though California's climate tends to be milder than the rest of the U.S., the energy savings driven by Nest Thermostats are still significant and impactful and could serve as a cost effective addition to residential energy efficiency program portfolios. The percentage savings results estimated in this analysis (see Section 3) are comparable to the percent savings from billing analysis studies from other regions. The Energy Savings white paper, which included results from across the U.S., found 10-12% of heating usage savings and electric savings equal to about 15% cooling usage.[2] The results of this analysis of California thermostats estimates average savings on the very same order-of-magnitude as the white paper:11.5% of cooling use savings and 15% of heating use savings.This analysis used data only from California thermostats and leveraged a different methodology than the studies summarized in the White Paper above. As such, it is affirming to have found savings results that are so similar. It is worth noting that the percent savings are similar, as expected, but that the absolute savings values shown are lower for CA customers than customers in less mild climates (this result is to-be-expected).

1.1 Supplemental data for California work paper

The purpose of this paper is to provide a supplemental energy savings analysis in support of a deemed measure work paper for smart thermostats in California. The analysis herein is based on more than 13 million days of data from more than 100,000 Nest Learning Thermostats across California and includes savings estimates by climate zone for both cooling and heating HVAC consumption (as well as electric savings from reduced furnace fan usage during the heating season).

1.2 Methodology Overview -- Leveraging the emerging EnergySTAR® metric

The overall energy savings estimation is based on four steps:

1. **Analyze Nest customer temperature set points to assess the efficiency of their schedules.** This analysis calculates average (i.e., mean) set points and "comfort temperatures" for the heating and cooling seasons for each customer. The "comfort" temperatures -- defined as the 90th percentile of the customer's heating set points and the 10th percentile of their cooling set points -- are meant to represent typical settings when people are home and want to be comfortable. This definition matches the current working definition being used by the EPA in their development of a smart thermostat metric for EnergySTAR® .

2. **Estimate the percent change in heating and cooling runtime per degree change in temperature set point using a regression model fit separately for each climate zone.** This step is also similar to the current EPA metric except it employs a pooled model rather than aggregating across individual device-specific models.

---

[1] Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results, Feb. 2015. https://nest.com/downloads/press/documents/energy-savings-white-paper.pdf
[2] Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results, Feb. 2015, p2.

3. **Estimate the heating and cooling energy savings compared to a constant set point at the comfort temperature.** The savings are calculated based on the savings per degree set point change found in step 2 and the difference between the average and comfort temperatures calculated in step 1. Again, this basic approach is being used in the EPA metric.
4. **Adjust the overall savings calculated in step 3 to account for customer's maintaining more efficient average baseline set points than a constant comfort temperature.** This step is not being used in the EPA metric because the EPA goal is to develop a metric of schedule efficiency. Energy savings could then be calculated as the difference between a thermostat's efficiency metric and the efficiency of any specified baseline condition

This methodology is based on actual customer temperature settings compared to an occupant's preferred comfort temperature (i.e. the temperature most likely "set" on manual thermostats or older programmable thermostats that are used in 'hold' mode or without an effective schedule). Temperature setbacks on smart thermostats, like the Nest Learning Thermostat, are driven by features like Auto-Schedule and Auto-Away that work to automatically generate more efficient schedules for customers.[3] As previously mentioned, the structure is quite similar to the current metric under development by EPA.

It is also worth noting that the software that drives smart thermostats, like the Nest Learning Thermostat, will only continue to improve over time, which will help to continuously improve the energy savings delivered by such devices (an encouraging concept given the already promising results included herein). For example, Nest now allows customers to leverage the location of their mobile phones as an added data point to help inform the Auto-Away feature.

1.3 Model input data
This analysis was conducted with actual data from some Nest Thermostats currently in use throughout the state of California. Most notably, the model is built on the following data:

- The average set points and comfort temperature calculations were based on heating and cooling runtime weighted averages for more than 150,000 Nest thermostats in California with data covering the full year of May 2015 through April 2016.
- The pooled fixed effects regression modeling, which assessed the energy savings per degree set point change, was based on data from more than 100,000 thermostats and included more than 6M device-days of heating data (from January, 2016 - February, 2016) and more than 7M device-days of cooling data (from July, 2015 - September, 2015). The regression model sample was restricted to single stage HVAC systems to avoid the uncertainty introduced by the unknown relative capacities of the stages.

2.0 Methodology Details

### 2.1 Determining individual customer comfort temperature
The methodology leverages the concept of a comfort temperature, which can be thought of as the temperature at which a given individual prefers to keep their home during a particular season.

---

[3] For more details on Auto-Schedule, please visit https://nest.com/support/article/How-does-Auto-Schedule-learn; for more details on Auto-Away, please visit https://nest.com/support/article/What-is-Auto-Away; and for details on the new enhancement to Auto-Away that allows customers to leverage the location fo their mobile phones, please see this description of our new Home/Away Assist feature https://nest.com/blog/2016/03/10/introducing-family-accounts-and-home-away-assist/

- ○ **Heating season comfort temperature:** a customer's preferred temperature during the Winter.
  - ■ Defined as the 90th percentile of target temperature setpoints for a particular customer throughout a heating season (i.e. only 10% of the time during the heating season does this customer have a warmer temperature setpoint).
  - ■ This comfort temperature is automatically calculated by each Nest Thermostat for each month. The seasonal average comfort temperature for each customer was calculated as the heating run-time weighted average across the season.

- ● **Cooling season comfort temperature:** a customer's preferred temperature during the Summer.
  - ○ Defined as the 10th percentile of target temperature setpoints (i.e. only 10% of the time during the cooling season does this customer have a cooler setpoint).
  - ○ Same calculation approach as for heating season.

Figure 1 shows heating comfort temperatures for a few customers compared with time series plots of hourly temperatures.
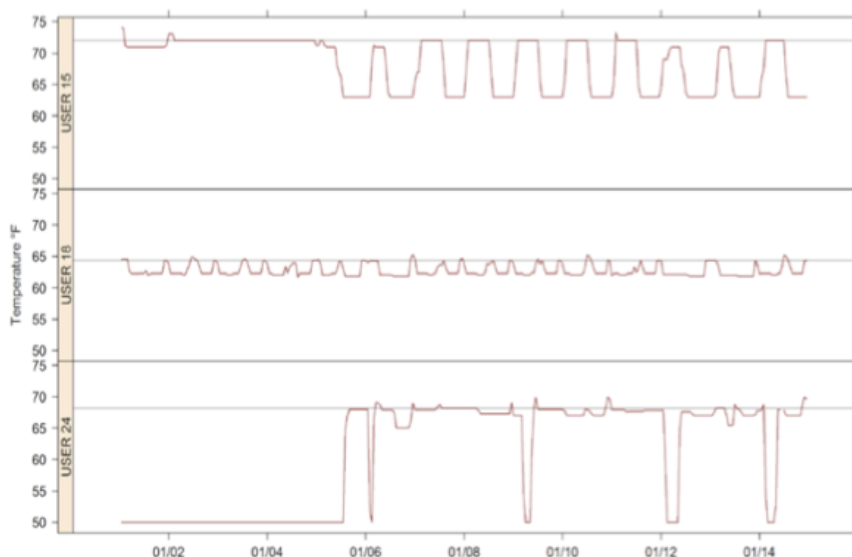

Figure 1: "Comfort" temperature = 90th percentile of heating setpoints. This chart shows that comfort temperature, in this case at the 90th percentile, can be reliably calculated and subsequently compared to average setpoints. As you can see, the 90th percentile is a good characterization of the common temperature people prefer when they are at home and want to be comfortable.
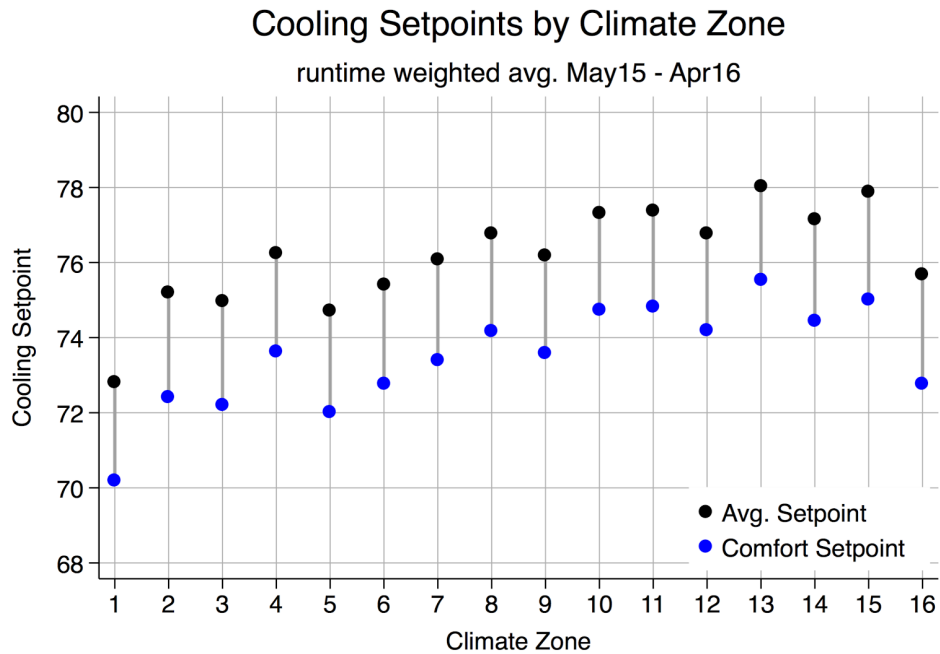
2.2 Average setpoints vs. comfort temperature

The comfort temperature described above defines a baseline condition of a flat schedule (i.e. one without heating set-backs or cooling set-ups). The difference between the actual average setpoints and the comfort temperatures for each device is a measure of the efficiency of each customer's schedule resulting from Nest's feature set and customer preferences. We recognize that the flat comfort temperature baseline may understate the efficiency of prior thermostat setting behaviors and so we added a final step to adjust the calculation results to reflect a more efficient baseline.

Figures 2 and 3 below show the average comfort temperatures and average setpoints aggregated by climate zone. The connecting lines in each chart illustrate the impact of setbacks on the set point.
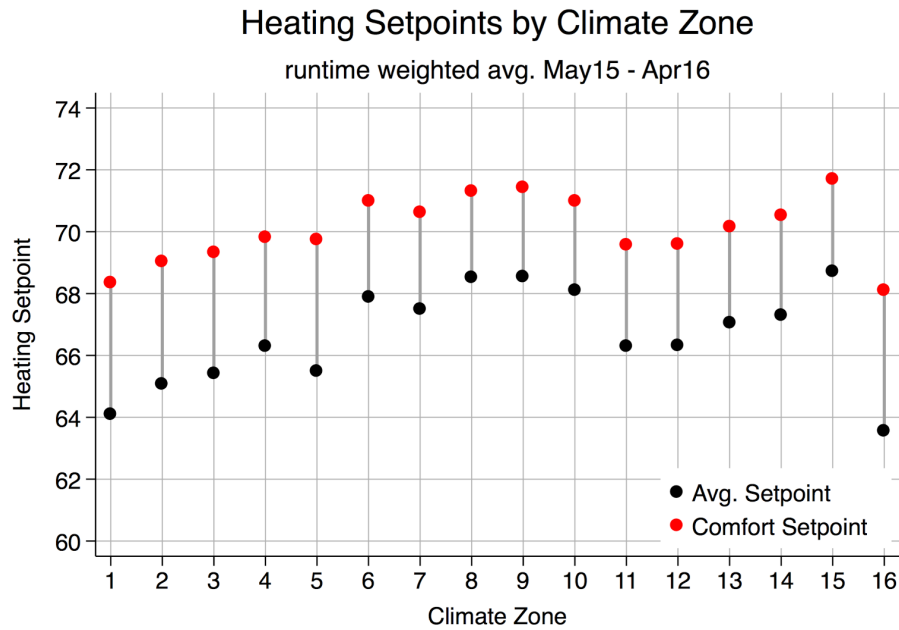
Figure 2: Heating setpoints by climate zone (runtime-weighted average May 2015 - April 2016). The data show a clear difference between comfort temperature and average setpoints. This difference drives a decrease in HVAC runtime and therefore energy savings.

Figure 3: Cooling setpoints by climate zone (runtime-weighted average May 2015 - Apr 2016). The data show a clear difference between comfort temperature and average setpoints..

2.3 Pooled Fixed Effects Regression Model

The analysis of set points provides an estimate of the difference between the baseline comfort temperature and the average actual set points for each thermostat. The impact of these changes on HVAC run time, and on energy use, need to be estimated. The next step in the analysis was to fit a pooled fixed effects regression model to estimate the impact of thermostat set points on HVAC run time, accounting for weather. This analysis estimates the HVAC runtime savings expected from each °F reduced from an occupant's comfort temperature. This regression analysis modeled average daily HVAC runtime as a function of degree days (HDD60 for heating and CDD65 for cooling) and average set point and included thermostat level fixed effects. A separate model was fit for each climate zone. The output of the regression models -- expressed as percent HVAC runtime reduction per degree F -- are shown in Section 3.

2.4 Calculating energy savings

After fitting the regression models, the raw percent energy savings for each climate zone were calculated as the difference between comfort and actual set points multiplied by the percent savings per degree F for that climate zone. These percent savings were then used to estimate kWh and therm savings by multiplying them by the product of the average heating and cooling run times in each climate zone and the estimated system input capacities (as estimated by a climate-based Nest algorithm, discussed in Section 3). The raw savings from these calculations were then adjusted for a more efficient baseline.

2.5 Correction for flat schedule

Although many manual thermostats, as well as many programmable thermostats, are often kept at their occupant's comfort temperature, some customers practice more efficient behaviors and already setback their temperature during the day or at night. Based on an analysis of customer survey data,[4] and results from M&V studies of Nest deployments in other regions of the country, we estimate that prior customer behaviors may already be achieving about one third of the schedule efficiency savings calculated from the flat temperature baseline approach. As a result, and to be conservative, we have reduced the savings estimates by a factor of ⅓.

2.6 Calibration to other smart thermostat studies

In order to assess the reasonableness of the ⅓ factor for reduction, we compared the calculated savings values (shown in Section 3 below) to those found by the SoCalGas (SCG)/Navigant study of smart thermostats. Our estimates are slightly lower than the SCG study -- 14 therms from this current analysis (based on a weighted average across pilot project zones) compared to 18 therms in the SCG study. In addition, the results of this method applied to thermostats in Indiana produce a slightly lower savings estimate than found by two utility billing analysis studies of Nest installations in Indiana. Both of these comparisons confirm our team's perspective that this adjustment factor is reasonable and conservative.

---

[4] Based on an ongoing survey of new Nest customers that was first deployed in April, 2016, after a meeting on the topic with the California Technology Forum (CalTF). Because it is a new survey and responses are just beginning to come in, this part of the analysis was limited. The sample size of this survey will continue to grow over time and Nest is prepared to share updates on this data in the coming months.

3.0 Results

3.1 Heating and cooling savings by CA climate zone

Table 1 shows the key results from the analysis by climate zone. The T-diff columns shows the average difference between the comfort temperature and actual average set point for each climate zone. The % Savings/°F columns show the estimated percent change in HVAC run time per degree change in set point. The Savings columns show the overall results from calculating energy savings using the T-diff and % Savings/°F columns in a calculation with the average annual HVAC run time hours (for the period May 2015 through April 2016) and the estimated average HVAC system input capacities, and then reducing those savings by one third to account for a more efficient baseline.

Table 1: Savings by CA Climate Zone. This table shows that the analysis found meaningful kWh and therm savings across California's climate zones (no results shown for Climate zone 1 because of a limited sample size of data). Absolute savings values are higher inland, but still impactful in coastal zones.

Climate Zone	Cooling			Heating			
	T-diff °F (comfort -actual)	% Savings /°F (regression)	Savings (kWh)	T-diff °F (comfort -actual)	% Savings /°F (regression)	Savings (therms)	Savings (kWh Fan)
CA1	sample too small						
CA2	-2.79	-8.1%	133	3.96	9.5%	43	35
CA3	-2.77	-7.6%	91	3.91	9.5%	40	25
CA4	-2.63	-7.8%	103	3.54	8.7%	29	23
CA5	-2.71	-6.1%	83	4.27	7.9%	27	19
CA6	-2.64	-7.8%	114	3.08	9.1%	14	11
CA7	-2.68	-7.6%	121	3.14	9.6%	13	11
CA8	-2.60	-7.5%	154	2.79	8.0%	11	10
CA9	-2.60	-7.0%	223	2.89	7.5%	16	19
CA10	-2.56	-8.2%	211	2.88	8.2%	13	15
CA11	-2.56	-10.1%	281	3.29	9.7%	31	38
CA12	-2.57	-9.0%	191	3.26	9.4%	31	34
CA13	-2.50	-9.6%	343	3.11	9.8%	25	31
CA14	-2.70	-8.9%	295	3.22	9.0%	35	37
CA15	-2.86	-9.2%	421	2.99	10.8%	10	15
CA16	-2.93	-8.4%	180	4.56	7.8%	77	47

3.2 System sizing assumptions shown in Table 2

Table 2: System Sizing Assumptions. These values are averages across thermostats and were generated based on an automated system sizing algorithm developed by Nest and primarily driven by local design temperatures. These assumptions can be easily changed if any sources are available from California-specific research.

California Climate Zone	Air Conditioner kW	Furnace Btu/hr	Furnace Fan kW
CA1	Not used		
CA2	3.43	58895	0.49
CA3	2.28	53397	0.33
CA4	2.62	55165	0.44
CA5	2.30	57544	0.41
CA6	2.03	45723	0.37
CA7	2.33	48991	0.41
CA8	2.74	51543	0.48
CA9	3.75	54349	0.66
CA10	3.64	55694	0.64
CA11	4.09	60441	0.72
CA12	3.78	59338	0.66
CA13	4.15	60476	0.73
CA14	4.28	71035	0.75
CA15	4.27	54380	0.77
CA16	3.52	81337	0.50