Energy Trust of Oregon Resideo Thermostat Optimization Pilot Report

Submitted by Apex Analytics, LLC
February 25, 2020

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1. Executive Summary

This report presents the findings from Energy Trust of Oregon's (Energy Trust's) Resideo (formerly Whisker Labs) Connected Savings Pilot ("Connected Savings Pilot").[1] The Connected Savings Pilot offers existing Portland General Electric (PGE) Bring-Your-Own Thermostat (BYOT) Demand Response (DR) Pilot ("PGE DR Pilot") participants an opportunity to optimize their thermostat setpoint and schedules for potential energy efficiency savings. Energy Trust hired Apex Analytics (Apex) to estimate the winter and summer electric (kWh) and natural gas (therm) savings associated with the Connected Savings Pilot. This report details the findings from the 2018/2019 winter and 2019 summer seasons.

According to combined runtime and billing analysis, the Resideo Connected Savings service achieved significant energy savings for the 2018/2019 winter heating season and 2019 summer cooling season. Combined runtime and billing analyses found reductions of 3.2% primary heating fuel savings and 5.1% fan electric savings for thermostats connected to furnaces. For heat pumps, we found reductions of 4.0% of heating electric use. For central air conditioning systems, we found reductions of 3.9% of cooling electric use. These reductions are shown in absolute and percentage energy savings in Table 1.

Table 1. Combined Per-Thermostat Energy Savings for the Connected Savings Pilot, by System and Fuel Type

System	Season	Fuel	TMY* Savings	90% CI*	Relative Precision	Savings as % of TMY Heating or Cooling Load
Gas Furnace	Winter	Therms	16	±7	±44%	3.2%
Electric Furnace**		kWh	414	±170	±41%	3.2%
Furnace Fan***		kWh	49	±22	±45%	5.1%
Heat Pump		kWh	177	±146	±82%	4.0%
Air Conditioner	Summer	kWh	31	±26	±84%	3.9%

* TMY–Typical meteorological year; CI–Confidence interval.
** Electric Furnace values calculated using Gas Furnace values converted to kWh.
*** Furnace fan savings are calculated from the weather-dependent electricity consumption of homes with gas furnaces

[1] In May 2019, Resideo Technologies acquired energy efficiency technology from Whisker Labs and hired the team behind it.

Resideo Connected Savings offers thermostat schedule optimization for energy efficiency on a broader range of thermostats and uses a different optimization approach than the Nest Seasonal Savings service. However, we found minimal overall differences in savings and opt-out frequency[2] between the two services, with the caveat that we adjusted our estimated savings in winter to exclude software issues that were not corrected until after the winter season concluded. The Nest Seasonal Savings Pilot ("Seasonal Savings Pilot")[3] did not have these issues and therefore no correction was needed.

Conclusion 1: The Resideo Connected Savings Winter and Summer service provided significant gas and electric savings, at similar levels to the Nest Seasonal Savings service. The precision of the winter savings estimate was lower for heat pumps and air conditioners (82% at 90% confidence) than for natural gas furnaces (44% at 90% confidence).

> ***Recommendation 1:*** *Energy Trust should adopt the per-thermostat savings values shown in Table 1 for future Connected Savings schedule optimization programs. If Connected Savings is expanded into a larger program, Energy Trust could use a similar design to this study for heat pumps only to revisit auxiliary heating use and the precision of the savings estimate. Future programs should measure savings for a larger sample of heat pumps (>1,000) and air conditioners (>2,000) in the treatment group to improve the precision levels.*

Conclusion 2: The promise—and benefits—of an expanded schedule optimization service across multiple thermostat vendors were diminished by data connectivity and functionality issues. In particular, the PGE DR service conflicted with the Energy Trust schedule optimization service, while the ecobee API experienced disruptions to connectivity and suffered interim data loss.

[2] This study did not include customer feedback; comfort levels were estimated based on surveys from Seasonal Savings and opt-out rates.

[3] Apex Analytics, Demand Side Analytics, "*Energy Trust of Oregon Nest Thermostat Seasonal Savings Pilot Evaluation*", November 22, 2017. Available online at: https://www.energytrust.org/wp-content/uploads/2017/12/Energy-Trust-of-Oregon-Nest-Seasonal-Savers-Pilot-Evaluation-FINAL-wSR.pdf

> ***Recommendation 2:*** *Future multipurpose solutions to digital DR and energy efficiency needs should be vetted to ensure that both services can be delivered seamlessly without one impacting the other. Future evaluations of third-party thermostat algorithm services should plan for the possibility of data loss when conducting power analysis.*

Conclusion 3: The Resideo Connected Savings service impact on participants' home comfort levels is uncertain.

> ***Recommendation 3:*** *While it is appropriate to consider the qualitative findings on comfort from the Seasonal Savings Pilot as a proxy for the Connected Savings Pilot, Energy Trust should consider a survey similar to the one conducted for the Seasonal Savings Evaluation to assess home comfort and satisfaction with the Pilot.*

Conclusion 4: The Resideo Connected Savings Summer service provided significant electric savings, higher than the Nest service. The precision of the savings estimate was low (80% at 90% confidence) but still significant. Our combined runtime and billing analyses found reductions of 3.9% savings for central air conditioning systems.

> ***Recommendation 4:*** *Energy Trust should adopt the per-thermostat savings values shown in Table 1 for future Connected Savings seasonal optimization programs.*

MEMO

Date: March 20, 2020
To: Board of Directors
From: Dan Rubado, Evaluation Project Manager
Ryan Crews, Residential Program Manager
Jackie Goss, Sr. Planning Engineer
Subject: Wrap-up Memo for the Resideo Thermostat Optimization Pilot

Introduction

In 2018, Energy Trust was presented with an opportunity to work with Portland General Electric (PGE) to test a new thermostat optimization software service developed by Whisker Labs (now Resideo). According to Resideo, its optimization service could save energy with any internet-connected thermostat by creating more aggressive setbacks at times least likely to impact occupant comfort. In addition to thermostat optimization, Resideo sends regular communications to customers that include HVAC system performance compared with others and tips to save energy. Resideo paired this thermostat optimization service with demand response (DR) capabilities under a single platform branded “Connected Savings.” The ability to work with utilities to do both thermostat optimization and DR was appealing, as was the ability to work across thermostat manufacturers, including models without any smart features.

Pilot Design

PGE’s DR pilot with Resideo provided a good opportunity for Energy Trust to test Resideo’s optimization service in conjunction with the DR service at a low cost. Energy Trust designed an experiment that would run on top of PGE’s DR pilot. When PGE customers signed up for the DR pilot, they were also asked to agree to the terms of the optimization service and were then randomly assigned to treatment and control groups. In this way, Energy Trust was able to conduct a randomized controlled trial to test the impact of the optimization service on home energy usage, independent of the DR service. Apex Analytics was hired as the evaluator to analyze the energy savings from the pilot. For the pilot, Resideo rolled out the Connected Savings optimization and DR services to ecobee and Honeywell internet-connected thermostats.

Summary of Findings

Overall, we learned the following from the pilot. Each point is discussed in more detail below.

- There were technical issues with the optimization service that affected the evaluator's ability to determine energy savings. The level of certainty in the savings results was lower than expected.
- The evaluated heating energy savings were small but significant and comparable with Nest's Seasonal Savings service. In addition, significant cooling savings were demonstrated. Although savings are somewhat uncertain, Energy Trust will adopt the values in the evaluation report for use in future campaigns because they represent the best available information and they are similar to previous thermostat optimization results obtained from Nest Seasonal Savings.
- The pilot was conducted in Western Oregon, so the results only reflect heating and cooling savings for the climate zones within that region.
- Additional research is needed to determine if Energy Trust's assumed one-year measure life for thermostat optimization services is valid.
- There was a low level of attrition from the pilot, with only a small number of customers opting out due to discomfort.
- Due to the acquisition of Whisker Labs by Resideo (i.e. Honeywell), it is unlikely that the Connected Savings optimization service will be expanded to other thermostat brands.
- One possibility for achieving additional savings through smart thermostats in the future is the manufacturers' ability to diagnose HVAC system issues remotely and alert customers.
- Energy Trust is currently enrolling customers in Resideo's thermostat optimization service and hopes to achieve significant participation numbers by the end of 2020.

Technical Issues with Thermostat Optimization

The evaluation of the Resideo thermostat optimization pilot did not provide the clear-cut results we would normally expect from a randomized controlled trial. There were two major technical glitches Resideo encountered during the implementation of the pilot that both reduced savings and made it more difficult to measure the true impact of the optimization service. Rather than working in tandem with each other, Resideo's optimization and DR services had a conflict when they were deployed together in the same home. During PGE's DR events in February 2019, homes in the optimization treatment group that received the DR signal responded erratically, in some cases overriding the DR events and in other cases dropping setpoints much lower than intended. Resideo says it resolved the issue, but it still disabled daytime optimization in some affected devices to reduce the risk of further DR conflicts. More testing needs to be done by Resideo to ensure the proper staging of optimization and DR services. However, Resideo has assured Energy Trust it has fixed the issue and can now roll out DR events on top of optimization setbacks by temporarily disabling optimization during DR events.

In a separate incident, Resideo accidentally delivered the optimization service to the pilot's control group for the last six weeks of summer. Both of these issues decreased the initially observed energy savings, but these effects were factored out in the evaluation since these events were expected to be one-time glitches.

In addition to the implementation issues, Resideo encountered problems obtaining runtime data from the two thermostat manufacturers, which was intended to be used in the evaluation of the service. Resideo had problems with the Application Programming Interfaces (APIs) that allowed it to access data form ecobee and Honeywell thermostats, which caused data to be lost for some devices. There was also an extended period during the winter season when thermostat connectivity issues and server outages caused widespread data loss. For the summer season, many devices did not have a sufficient history of data going back to the previous summer to conduct a pre/post analysis. These issues, combined with smaller data quality issues, added up to a loss of roughly 30% of sites from the winter runtime analysis and nearly 60% of sites from the summer runtime analysis. There were also significant losses in data coverage for those sites that remained.

This level of data loss substantially increased the error bounds of the results and, more importantly, may have disrupted the randomized design of the study and introduced bias. It is difficult to assess the impact of this bias, but we do know that the remaining treatment and control groups were not equivalent in the baseline period. Fortunately, the evaluation was able to independently assess savings through monthly billing analysis, where levels of attrition were roughly 10%, comparable with typical billing analysis. However, the billing analysis results were imprecise due to the monthly nature of the data and high variability compared with the magnitude of savings. The results of the runtime and billing analyses were combined to improve the precision and hedge against possible bias.

Energy Savings Results

The evaluation results show significant winter heating savings for gas furnaces, electric furnaces and ducted heat pumps. In addition, the evaluation observed a small amount of summer cooling savings for central air conditioners and ducted heat pumps. These results are dependent on typical weather and the absence of technical glitches. They also assume that customers will continue to receive regular communications from Resideo about HVAC system performance and energy saving tips. While these results are not as precise or definitive as we hoped to see, they do indicate Resideo’s optimization service produces small but statistically significant energy savings across the board and are comparable to energy savings from Nest’s Seasonal Savings service. The pilot’s findings and energy savings values will be incorporated as deemed savings into an updated Measure Approval Document and measure cost-effectiveness screening.

Savings Beyond PGE Territory

The pilot was conducted in PGE territory in Western Oregon, so the findings don’t provide any information about potential heating savings in Oregon’s other climate zones. Heating savings may differ in the colder climates east of the Cascades, and cooling savings may differ in regions with hotter summers like Southern Oregon. In the short term, Energy Trust may assume heating and cooling savings simply scale with weather differences in different climate zones.

As Energy Trust rolls out the Resideo Connected Savings service on a larger scale, we will continue to assess savings, especially in regions not included in the pilot. Energy Trust plans to hold back a random 10% of enrollees in the service as a control group and continue to collect runtime data from Resideo. Once a sufficient number of participants are enrolled and have been treated with the Resideo service for a full year, Energy Trust will be able to re-analyze energy savings and make distinctions between climate zones. At that juncture, Energy Trust may also be able to analyze pilot participants no longer enrolled in the service to assess persistence.

Measure Life

Energy Trust currently assumes a one-year measure life for both Nest Seasonal Savings and Resideo Connected Savings. However, it is unclear how long savings from either of these services would persist if participating thermostats stopped receiving commands through their respective services. It is also not known if savings continue to grow year over year if a device stays enrolled in the optimization service. There is some reason to believe the Nest and Resideo algorithms function differently and that persistence may differ accordingly. Research on the persistence of savings is needed but may be challenging because it requires a high degree of collaboration and data sharing with Nest and Resideo.

Participant Satisfaction and Attrition

While planning the pilot, Energy Trust was concerned about participant satisfaction and comfort, given the optimization service achieves savings by setting thermostats to less comfortable temperatures. Although the evaluation did not involve customer surveys or a direct assessment of comfort, it did monitor opt-outs and other types of attrition reported by Resideo. Through the pilot evaluation, we learned the attrition rate was about 5% in winter and 3.5% in summer, including opt-outs, disconnections and move-outs. About 40% of attrition came from opt-outs, which were primarily due to discomfort, as reported by Resideo. Given that participants could override the automated setbacks and were given the option to opt-out at any time, we believe that 5% attrition demonstrates an acceptable level of comfort was maintained in most homes. We plan to follow up on this question in 2020 with a participant survey to assess satisfaction and comfort.

Expanding to More Thermostat Brands

Energy Trust was originally interested in Resideo's ability to work with many different thermostat manufacturers and had hoped to expand coverage of thermostat optimization across major brands. Unfortunately, the future of the Resideo optimization service will likely focus on Honeywell thermostats since Resideo is a spinoff from Honeywell, encompassing Honeywell's thermostat business line. Resideo acquired Whisker Labs part way through the pilot and is unlikely to expand the reach of its optimization service to its competitors. While this does limit the future potential of Resideo's optimization service to Honeywell thermostats, it should be noted that Honeywell is a dominant thermostat brand in the region and has a large base of existing devices.

Separately, ecobee has developed an optimization service called eco+, which it is rolling out to all customers with no involvement from utility programs. This may have the effect of increasing the base level of energy savings for ecobee thermostats that enroll in the eco+ service without the need for Energy Trust to coordinate further intervention.

Future Diagnostic Services

Nest, Resideo, and ecobee have all been developing algorithms to identify potential HVAC system issues by monitoring thermostat runtime and temperature data. This is an area of interest for Energy Trust and may warrant further research. Once a potential issue is identified, the vendors could notify the customer and refer them to an HVAC contractor in their area. This ability to help identify maintenance issues early and encourage customers to fix them could result in additional savings from improved system performance. Further investigation is needed to determine how well these algorithms work, what types of maintenance issues can be identified and resolved, and how much energy savings might be expected. It is unclear how Energy Trust would be involved in this process, but we could potentially identify a pool of trade ally contractors to work with or provide incentives to reduce the cost of maintenance work.

Next Steps

Energy Trust is currently enrolling participants with Honeywell thermostats in Connected Savings across the state. Post-pilot uptake of the optimization service has been limited, primarily due to less effective recruiting methods employed by Resido compared to PGE during the pilot. In addition, there is no customer facing incentive for opting into Connected Savings, which differs from the pilot, where PGE provided incentives to get customers enrolled in the DR portion of the pilot. However, Energy Trust is investigating alternative recruiting methods and hopes to obtain more participants by the end of 2020. This will allow for additional research, including research on savings in other climate zones, measure life, participant satisfaction and integration with DR.

Between Nest Seasonal Savings, Resideo's Connected Savings, ecobee's eco+ service and optimization services being developed by other thermostat manufacturers, Energy Trust sees a large amount of savings potential in thermostat optimization if it can reach a broad cross-section of homes across the state.

2. Background

Over the past six years, Energy Trust has been at the forefront of thermostat pilot research and program design. Thermostats, including wi-fi and advanced smart models, represent an ongoing opportunity for Energy Trust's residential programs. Energy Trust initially offered a smart thermostat pilot focused on Heat Pumps[4] and has since expanded that offering to include smart thermostats paired with gas furnaces ("Gas Furnace Thermostat Pilot").[5] More recently, Energy Trust has shifted its focus to software-driven thermostat pilots, including the Nest Seasonal Savings Thermostat Optimization Pilot. The Seasonal Savings Pilot reported cost-effective savings[6]; however, the opportunity was limited to customers with Nest thermostats. Energy Trust sought to expand the software-driven smart thermostat offering, and their Residential program implementation contractor, CLEAResult, proposed a pilot with Whisker Labs (now Resideo). While the Resideo schedule optimization service expanded thermostat software optimization to more devices, the savings impacts were still relatively unknown.

The Resideo Connected Savings platform works with multiple Wi-Fi thermostat brands, including Honeywell, ecobee, Carrier, and Emerson, to provide DR and additional energy-saving schedule optimization via each manufacturer's Application Programming Interface (API). The Connected Savings Pilot tested the Resideo platform's potential to achieve energy savings through automated schedule optimization of thermostats. The Connected Savings Pilot started with the study group from the ongoing PGE DR Pilot[7] with Resideo. The PGE DR study population was randomized into treatment and control groups to test the addition of the Connected Savings schedule optimization service.

The Connected Savings schedule optimization service had many uncertainties around delivery and savings, listed below:

- Unknown savings

4 Apex Analytics, "Energy Trust of Oregon Nest Thermostat Heat Pump Control Pilot Evaluation," prepared for Energy Trust of Oregon (October 2014); With follow-up memo: "Follow-up Billing Analysis for the Nest Thermostat Heat Pump Control Pilot"

5 Apex Analytics, "Energy Trust of Oregon Smart Thermostat Pilot Evaluation," prepared for Energy Trust of Oregon (March 2016).

6 Apex Analytics and Demand Side Analytics, "Energy Trust of Oregon Nest Thermostat Seasonal Savings Pilot Evaluation," prepared for Energy Trust of Oregon (November 2017).

7 Study ongoing, not yet published.

- Uncertain customer acceptance
- Undetermined costs to run a standalone schedule optimization program for energy savings (without DR)

The Connected Savings Pilot was launched to explore potential energy savings associated with the Resideo Connected Savings service. The primary research questions of the Connected Savings Pilot were as follows:

- What are the winter (heating) and summer (cooling) savings associated with Resideo Connected Savings?
- Are there variations in energy savings between different heating systems?
- What are customer opt-out and disconnect rates?

To help answer the Connected Savings Pilot research questions, the primary objectives of this evaluation were as follows:

- Independently evaluate electric and natural gas energy savings using both thermostat runtime and customer billing data.
- Identify statistically significant differences between different heating systems.
- Estimate customer opt-out and disconnect rates.

2.1 The Resideo Connected Savings Service

The Resideo Connected Savings service claims to offer automated energy-efficiency savings by optimizing thermostat schedules and reducing HVAC system runtimes. The service works with several different Wi-Fi connected thermostat models and, while it is compatible with advanced smart thermostats, they are not a requirement for the service. The Connected Savings service makes thermostat schedule and setpoint adjustments by comparing system runtime data from connected devices to weather data and making schedule adjustments with varying levels of aggressiveness to reduce system runtime at optimal times while maintaining comfort. Currently, compatible thermostats include Honeywell, ecobee, Carrier, and Emerson, although only Honeywell and ecobee thermostats were contracted for the Connected Savings Pilot. To qualify for participation in the service, the Wi-Fi thermostat must be connected to the internet, and cannot be on a permanent hold, which would block schedule adjustments through the service.

Energy Trust chose to pilot the Resideo Connected Savings service because it offered several different features that the Nest Seasonal Savings service did not. A summary comparison of the Resideo Connected Savings relative to the Nest Seasonal Savings service is shown in Table 2 below.

Table 2. Resideo Connected Savings versus Nest Seasonal Savings

Features	Nest	Resideo
	Seasonal Savings	Connected Savings
Permanent Setpoint Adjustment	•	
Active (Daily) Schedule Optimization		•
Weather Utilization		•
Behavioral Messaging		•
Multiple Thermostat Brands		•
Proprietary Thermostat	•	

The Resideo Connected Savings service gives users the option to choose how much the service prioritizes savings versus comfort, which guides how aggressive the algorithm is. This is initially established during the participant intake process, where participants are asked to create a "Home Profile." The Resideo Connected Savings service algorithm offers users three options, which range from the most comfort-based setting ("Comfort"), to the most savings focused settings ("Savings"). The middle option ("Default") is automatically selected if users do not choose a profile. Users are able to change the profile settings at any time.

The Resideo Connected Savings service also includes a behavioral service oriented towards participant thermostat and general residential energy usage. Connected Savings participants receive a monthly "Scorecard", which is a report on their runtime and historical setpoints and provides customized, actionable tips to save energy. Scorecards are delivered on a monthly basis via email, with active hyperlinks to the user portal where participants can view current and historical usage reports. The Scorecard module ranks the efficiency of their settings over the course of the previous month based on the average day's setpoint schedule. For the Connected Savings Pilot, only Honeywell thermostat participants received the Scorecards; ecobee users did not due to API connectivity issues.[8]

8 The ecobee historical data API was extremely limited until March 2019, and Resideo was unable to download sufficient data to produce reports required for the Scorecards.

As part of the Connected Savings Pilot, the Resideo implementation team tested a new approach to winter schedule optimization at the beginning of the 2018/2019 winter season. The new optimizations focused on nightly setbacks, between 2:00AM and 5:00AM. For heat pumps, the optimization gradually increased setpoints at the end of the setback period to avoid triggering auxiliary heat. The summer deployment for the Energy Trust pilot did not differ from previous deployments, although it did incorporate nighttime setbacks. It should be noted that nighttime setbacks have higher potential for savings because of the higher average nighttime winter heating load relative to the nighttime cooling load during the summer. Moreover, customers are likely to be less tolerant of increased temperature than of decreased temperature at night.

2.2 Participant Selection and Randomization

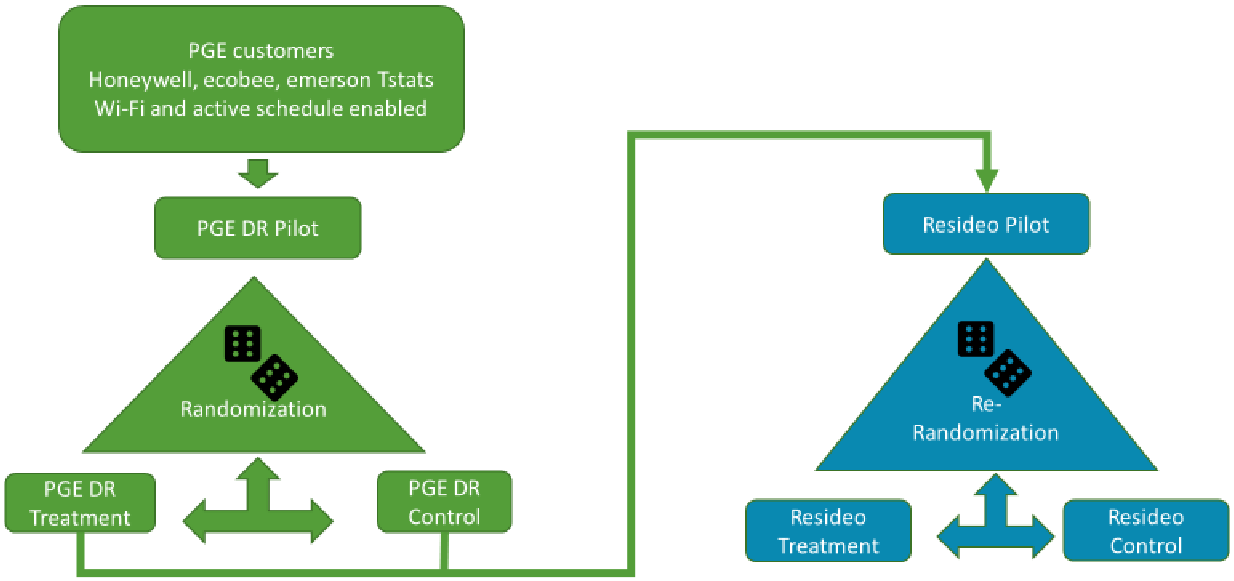
The Connected Savings Pilot utilized a Randomized Control Trial (RCT) approach for participant selection and for the evaluation. As noted above, PGE had offered the PGE DR Pilot in the fall of 2017. The PGE DR Pilot randomly assigned participants into treatment and control groups (termed PGE DR Pilot groups) to test the Connected Savings DR capabilities and demand reductions. Energy Trust and Resideo then conducted a separate randomization for the Connected Savings Pilot[9]; all currently enrolled PGE DR Pilot customers (i.e., both treatment and control) were randomly assigned to new treatment and control groups (termed Schedule Optimization groups) solely for the Connected Savings Pilot.[10] The intent of this separate randomization was to net out any cross-effects of the PGE DR Pilot with the Connected Savings Pilot.[11] Energy Trust staff managed the participant randomization, with the target of splitting the PGE DR Pilot population into 60% treatment and 40% control group sizes. The methodology for assignment into treatment and control groups for the PGE DR Pilot and Connected Savings Pilot is shown graphically in Figure 1.

[9] Note that, although Resideo offered both the PGE DR Pilot and Connected Savings Pilot, this report refers to the PGE DR Pilot groups as the PGE DR treatment and control groups, and the Connected Savings groups as the Resideo treatment and control groups.

[10] Once enrolled in the PGE DR Pilot, customers agreed to possible additional participation in efficiency optimization.

[11] Customers with multiple thermostats were placed into the same study group.

Figure 1. Resideo Connected Savings Pilot Participant Selection and Randomization



Note: Emerson thermostats were not included in the schedule optimization portion of the pilot.

Customers in the Resideo treatment group received the Resideo thermostat schedule optimization service for one winter heating and summer cooling season beginning in the winter of 2018 (December 4, 2018). Customers in the Resideo control group were not offered the schedule optimization service. To treatment group customer, the Connected Savings Pilot appeared as a new feature from Resideo (which also delivered the PGE DR Pilot) under the Connected Savings brand, rather than a separate service. Treatment group customers were automatically enrolled in the schedule optimization service, with the option to opt-out, and were not made aware of Energy Trust's involvement. Participation in the Connected Savings Pilot schedule optimization service was free, and no incentives were offered.[12]

A summary of the winter pilot participant randomized group totals is shown in Table 3 below and summer pilot participant totals in Table 4. The summer pilot air conditioning system type is inclusive of both "AC + Gas Furnace" and "heat pump" systems.

12 Participants in the PGE DR Pilot received payment(s) from PGE for their participation.

Table 3. Summary of Winter Connected Savings Pilot Participation

Winter Season		Resideo Control		Resideo Treatment	
System Type	Brand	Participants (Customers)	Thermostats	Participants (Customers)	Thermostats
AC + Gas Furnace	ecobee	318	326	466	482
AC + Gas Furnace	Honeywell	340	349	510	528
AC + Gas Furnace	Subtotal	658	675	976	1,010
Heat Pump	ecobee	193	198	278	279
Heat Pump	Honeywell	101	114	156	170
Heat Pump	Subtotal	294	312	434	449
Electric Furnace	ecobee	8	8	13	13
Electric Furnace	Honeywell	5	6	4	4
Electric Furnace	Subtotal	13	14	17	17
	Winter Total	965	1,001	1,427	1,476

Table 4. Summary of Summer Connected Savings Pilot Participation

Summer Season		Resideo Control		Resideo Treatment	
System Type	Brand	Participants (Customers)	Thermostats	Participants (Customers)	Thermostats
Air Conditioning	Ecobee	511	524	735	753
Air Conditioning	Honeywell	500	522	733	766
	Summer Total	1,011	1,046	1,468	1,519

2.3 Deployment

After the Connected Savings Pilot treatment and control group selection was completed, Resideo deployed the schedule optimization service to devices in the treatment group. According to Resideo documentation, the deployment included the following steps:

- Develop a thermodynamic model for each home
- Fine-tune thermostat schedules and setpoints each morning, which may include:
  - Shifting scheduled times (average time shift ~20 minutes)
  - Altering setback temperatures when home is believed to be unoccupied to maximize savings
  - Allowing overrides by user changes to temperatures and incorporate into future adjustments
- Incorporate future 24-hour weather forecast into the optimization

Resideo conducted rolling deployment of the schedule optimization service throughout the Connected Savings Pilot as new participants were enrolled into the study and randomized. The schedule optimization service is applied year-round based on home characteristics, anticipated weather, and the customers' schedule (i.e., the optimization is not strictly limited to summer/winter seasons and does not shut off during shoulder seasons). Across both seasonal deployments, a majority of users selected the "Comfort" setting, followed by the default setting; only 4% of the participants chose the more aggressive "Savings" setting in both seasons. A summary of the counts for treatment group setting is in Table 5 below.

Table 5. Connected Savings Pilot Settings

Season	Winter		Summer	
Setting	Participant Count	Participant Percent	Participant Count	Participant Percent
Comfort	770	54%	750	51%
Default	595	42%	663	45%
Savings	62	4%	55	4%
Total	**1,427**	**100%**	**1,468**	**100%**

2.4 Pilot Participant Attrition

At any time during and after the deployment, treatment and control group participants could leave the Connected Savings Pilot, either through actively opting out of the service, through disconnection of their device, or other reasons (e.g., moveouts). Resideo provided opt-out status as part of the data provided to Apex. A summary of the opt-out totals is shown in Table 6. Five percent of Resideo control participants and slightly over 8% of Resideo treatment participants left the Connected Savings Pilot across the two seasons. The most common reason for treatment group attrition was due to actively opting out of the service (n=48), followed by users who disconnected services (n=31). The attrition rates for the Connected Savings service were marginally higher than the Nest Seasonal Savings service, which were approximately 5%.[13]

[13] See Apex Analytics and Demand Side Analytics, Energy Trust of Oregon Nest Thermostat Seasonal Savings Pilot Evaluation, November 22, 2017. Report available at https://www.energytrust.org/wp-content/uploads/2017/12/Energy-Trust-of-Oregon-Nest-Seasonal-Savers-Pilot-Evaluation-FINAL-wSR.pdf

Table 6. Summary of Connected Savings Pilot Attrition

Season	Winter		Summer***	
Setting	Control	Treatment	Control	Treatment
Initial Total	965	1,427	1,009	1,468
Opted-out	0	32	3*	16
Disconnected	15	24	9	7
Other**	2	13	20	27
Total Attrition	17	69	32	50
Active users	948	1,358	977	1,438
Attrition percent	1.8%	4.8%	3.2%	3.4%

*Control opt-out was due to participant opting out of the PGE DR pilot.
**Other represents move-outs, no longer a PGE customer, or disqualification.
***Summer attrition includes spring and summer season (May-September).

Treatment customer who were "active" opt-outs of the Connected Savings Pilot were more likely to opt-out in the winter (there were twice as many opt-outs during the winter season, see Table 7 below). Active opt-outs were also more likely have AC + Furnace HVAC systems (AC + Furnace represented 88 percent of the treatment opt-outs relative to representing 68 percent of the treatment group).

Table 7. Summary of Connected Savings Pilot Opt-Outs

	Control		Treatment	
Season	AC + Furnace	Heat Pump	AC + Furnace	Heat Pump
Winter			28	4
Summer	3		14	2

A majority (n=30) of the active opt-out treatment customers did not provide any reason for their dropping from the Pilot. The most common reason for treatment customers that actively opted-out of the service was discomfort (n=4); participants believed the settings were too aggressive, resulting in cold homes in the morning (winter, n=3) or too aggressive pre-cooling in the mornings (summer, n=1). Other opt-out reasons provided by at least two customers included:

- Two treatment customers believed the service had dramatically increased their usage and accompanying bills.
- Two treatment customers had infants and were worried about their comfort.
- Two treatment customers believed they already had more conservative settings than the schedule optimization service.

2.5 Customer Communications

Resideo limited customer engagement and only conducted light-touch communication with the Connected Savings Pilot treatment group. Control group participants did not receive any communications related to the Connected Savings Pilot, although Resideo sent communications related to the PGE DR Pilot to customers in both treatment and control groups. All Connected Savings Pilot communications were branded by either the participant's thermostat manufacturer or by Resideo (using the Connected Savings brand). Energy Trust's brand was not used on communications.

Communications were limited to notifying customers of the schedule optimization deployment, which was sent upon enrollment in the treatment group, and customer engagement "Scorecards," which were sent monthly via email. The engagement scorecards encouraged uptake of optimized schedules and provided information about the optimization they have received.[14] Resideo noted the possibility that "sending this email will impact energy savings compared to a scenario where no engagement email is provided." Due to the relatively small number of total participants, there was no plan to test the engagement email separate from the rest of the efficiency service (i.e., everyone received the email). This choice means that any results of the Connected Savings Pilot will be contingent on any future offering also including these emails.

2.6 Data Management

Resideo receives customer sign-up and thermostat information from the thermostat equipment manufacturers. The Resideo dataset includes the following:

- Customer address and reported site characteristics
- Thermostat information and installation date (if available)
- Study group (treatment or control) and enrollment and/or activation dates
- HVAC operation modes, setpoints, and equipment runtimes and stage (including auxiliary heating minutes)
- Weather (temperature, humidity, but not precipitation)

14 Engagement Scorecard emails were only sent during the heating and cooling seasons.

The Resideo thermostat data included heating system breakouts for heating runtime based on system-controlled relays. Runtime data differentiated between single versus multistage cooling and whether the thermostats triggered a compressor or auxiliary heating system with a compressor or backup auxiliary only. The thermostat runtime data did not distinguish between electric versus gas furnace, but the presence of gas billing data allowed Apex to distinguish gas versus electric furnaces.

2.7 Data and Deployment Issues

The Connected Savings Pilot experienced several notable data acquisition and deployment issues that were important factors in this evaluation. The following issues occurred:

- Beginning in late 2018, ecobee thermostats changed their API (which allows access to thermostat data), putting severe limits on the data available for Resideo to acquire. The Resideo team was eventually able to resolve the API connectivity issue but still found that some of their API requests were being rejected or received empty responses for particular locations, which temporarily delayed the evaluation activities. It is unknown whether this had an effect on savings.
- In February 2019, both Honeywell and ecobee thermostats experienced severe outage issues. This outage occurred during a cold snap and due to server load, resulting in significant data loss, particularly for ecobee thermostats.
- Because the Connected Savings Pilot ran concurrently with the PGE DR Pilot, the dual algorithm approach to thermostat control eventually caused a conflict between these applications. The winter PGE DR Pilot events occurred exclusively in February 2019. Resideo also sent schedule optimization adjustments during the February DR events and having dueling algorithms caused the DR events to be overridden, while sending some of the ecobee thermostats to their minimum setpoint (e.g., 45 degrees). According to Resideo, these extreme events occurred for only a few customers but, to avoid the potential for additional conflicts and extreme events, Resideo decided to ratchet down the Connected Savings schedule optimization settings for the ecobee thermostats from that point in February and afterwards.[15] This likely had a more significant effect on the summer

15 The conflict between the PGE DR and Connected Savings, according to Resideo, should be resolved for the summer season. To avoid having the Connected Savings interfere with the PGE DR events, the Resideo optimization was minimized and did not run during the day when DR events were called, but still ran at night outside of the DR events. These changes occurred starting in February and afterwards, and not just on the DR days.

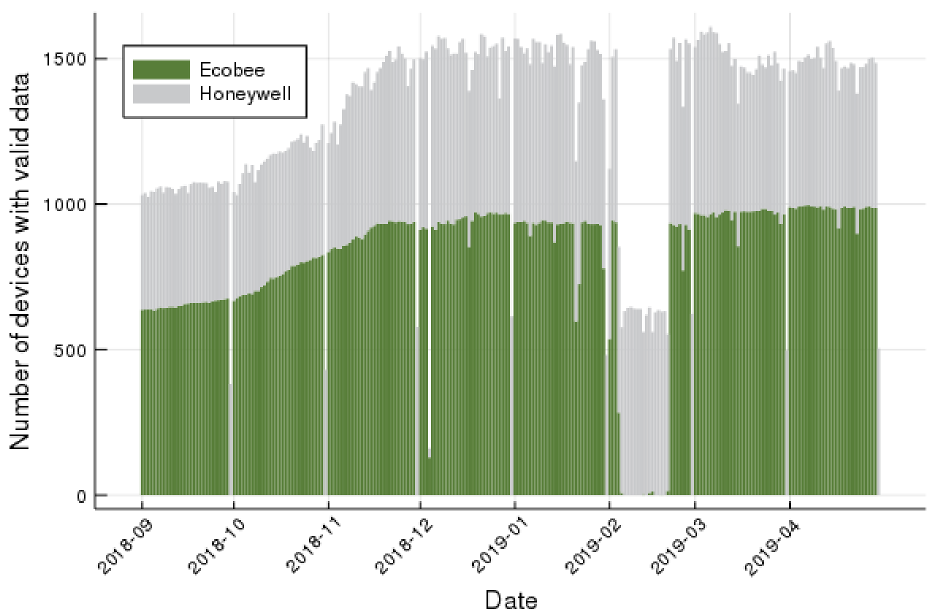
deployment, given the reduced magnitude for savings from nighttime optimization.

- Resideo developers accidentally delivered schedule optimization to the control group for the last six weeks of the summer pilot (Aug 13–Sept 30), switching them from the "Control" to the "Comfort" setting. Note that we investigated this issue and determined that because the Comfort setting applied very mild optimization, the benefit of including this group as a near-control group outweighed the loss of two months of data from the analysis. Initial testing indicated minimal impact to the results, except that excluding the time period where all customers were treated resulted in lower precision.

These data issues result in loss of data, which has impacts on the statistical power and resulting confidence of the analysis. However, the more pernicious impact is that they introduce uncertainty into whether the remaining data are biased, as the errors themselves may preferentially affect certain groups or certain types of days. While we triangulate estimates and check for reasonableness where appropriate, we recognize the potential unknown bias in the runtime results.

The number of online devices, by month and thermostat manufacturer, is shown in Figure 2. Note the data outage for ecobee thermostats in February of 2019.[16]

Figure 2. Number of Devices Online across the Pilot Period



[16] Resideo provided a new runtime extract in the fall of 2019 for the summer analysis. This runtime data mostly addressed the loss of data after an ecobee upgrade to their backend system allowed access to historical data. This made re-requesting the historical data much more successful. There was also increased interpolation used in the fall 2019 data files.

3. Overall Evaluation Approach and Data Sources

The Connected Savings Pilot evaluation included two primary analyses: a thermostat runtime analysis and a billing analysis. The Evaluation Team maintained as much consistency as possible in the analysis across seasons. To determine the energy savings impacts of the pilot, the Apex team relied on the following data sources:

- **Participant Data:** Resideo provided thermostat installation date, HVAC system type, home details, thermostat type, treatment or control group status.
- **Thermostat Runtime Data**: Resideo provided system runtime telemetry data, which included thermostat identification number, date/time of interval, setpoint temperature, runtime, schedule settings, and online status.
- **Billing Data**: Energy Trust provided monthly billing data, which included participant account numbers, read date, read period, electric kWh or gas therm usage, and rate codes. These data were linked to thermostat customer IDs through address matching performed by Energy Trust staff.
- **Weather Data**: Resideo provided indoor and outdoor temperature data within the thermostat telemetry data set, for all homes in the study. Apex collected historical weather data from PGE territory weather stations using the NOAA[17] Local Climatological Data web service for timepoints outside the time span of the thermostat telemetry data (e.g. for extrapolation to Typical Meteorological Year [TMY] or to analyze historical billing data[18]).

Apex conducted a series of data validation and cleaning procedures on each dataset we received. A summary of the data processing steps is reviewed below.

3.1 Data Cleaning and Validation

Apex staff conducted comprehensive data cleaning and validation on the pilot runtime and billing data. Because the deployment was a randomized control trial, it was important to retain as much data as possible from both groups. Similarly, we applied all data cleaning procedures equally to both groups to avoid introducing bias into the experiment. We checked for the following:

- Missing data, including incomplete temperature, runtime, or billing data.

17 NOAA weather data site: http://www.ncdc.noaa.gov/qclcd/QCLCD

18 For comparison with the Seasonal Savings evaluation, we extrapolated to TMY3. However, this data set is now 14 years old, and we recommend future investigations extrapolate across the preceding 10 years to account for changing climate.

- Inconsistent data according to reasonable expectations for runtime, temperature, or energy use. For example:
  - Conflicting records for the same thermostat timepoint
  - Zero energy use or runtime when expected (e.g. extended periods with no heating during winter or cooling during summer)
  - Unrealistic energy use (greater than 12 therms per day or 360 kWh per day)
- Participants lacking sufficient pre- or post-period records. Pre-period data should cover 10 days of the comparison period and post-period data should cover at least 30 days. While 10 days is a relatively short amount of time for comparison, participants who enrolled after the program start only required a 10-day window of data gathering before the program start. Therefore, that is where the inclusion threshold was set for the pre-period. Participants below these thresholds were removed from modeling.
- Hours with insufficient data. An hour was considered valid if it had 3 out of 4 intervals complete (allowing 1 imputed interval per hour).
- Days with insufficient data. A day was considered valid if it had 22 valid hours out of 24 (90% threshold).
- Low level of occupancy during the experiment, as determined by thermostats in vacation mode or months with very low energy use. This was flagged as a threat to external validity, but we did not remove accounts so long as they met data sufficiency requirements.
- Participants with no thermostat runtime during either season. These participants were removed from the analysis. We set a screen for total hours of heating runtime in the pre- and post-periods at a minimum threshold of 20 hours of heating or 12 hours of cooling in each period.

The winter runtime data processing attrition is summarized in Table 8 to Table 10 below. A significant portion of thermostats (approximately one-third) did not have sufficient pre- or post-period data. The attrition levels were highest for the electric furnace group, with over 50% loss of thermostats, while the AC + Furnace and heat pump thermostats averaged a 30% loss.

Table 8. Summary of Thermostat Runtime Data passing Each Filter - Gas Furnace Participants

Step	Treatment Counts	Treatment %	Control Counts	Control %
Initial (Participants w/ Data)	1,014	100%	674	100%
Sufficient Pre-period Data	796	79%	519	77%
Sufficient Post-period Data	832	82%	567	84%
Sufficient Pre-period Heating	875	86%	559	83%

Step	Treatment Counts	Treatment %	Control Counts	Control %
Sufficient Post-period Heating	911	90%	610	91%
Flagged as Approved	969	96%	661	98%
Temperature Data	988	97%	669	99%
Total Remaining Valid Participants	715	71%	462	69%

Table 9. Summary of Thermostat Runtime Data passing Each Filter – Electric Furnace Participants

Step	Treatment Counts	Treatment %	Control Counts	Control %
Initial (Participants w/ Data)	17	100%	14	100%
Sufficient Pre-period Data	13	76%	7	50%
Sufficient Post-period Data	13	76%	14	100%
Sufficient Pre-period Heating	12	71%	7	50%
Sufficient Post-period Heating	17	100%	13	93%
Flagged as Approved	17	100%	13	93%
Temperature Data	17	100%	14	100%
Total Remaining Valid Participants	7	41%	6	43%

Table 10. Summary of Thermostat Runtime Data passing Each Filter – Heat Pump Participants

Step	Treatment Counts	Treatment %	Control Counts	Control %
Initial (Participants w/ Data)	449	100%	312	100%
Sufficient Pre-period Data	397	88%	244	78%
Sufficient Post-period Data	388	86%	278	89%
Sufficient Pre-period Heating	413	92%	239	77%
Sufficient Post-period Heating	418	93%	280	90%
Flagged as Approved	429	96%	295	95%
Temperature Data	430	96%	312	100%
Total Remaining Valid Participants	351	78%	211	68%

The summer runtime data processing attrition is summarized in Table 11. Note that missing data early in the pilot, up to and during the initial enrollment period, led to substantially higher attrition than in the winter data. The percentage of hours with missing runtime data dropped from 45% to 20% across November 2018, in time for the winter pre-period, Figure 3. However, because the summer optimization started immediately following the winter optimization, the pre-period for most participants was in summer 2018, when most of the runtime data was not usable. This data set started with all supplied telemetry data from Resideo, and some participants did not have central air conditioning or heat pump systems, which also led to a reduced number passing pre- and post- period cooling screens (they would have no thermostat runtime in the cooling season).

Table 11. Summary of Thermostat Runtime Data passing Each Filter - Summer Savings Participants

Step	Treatment Counts	Treatment %	Control Counts	Control %
Initial (Participants w/ Data)	1,619	100%	1,095	100%
Sufficient Pre-period Data	915	57%	551	50%
Sufficient Post-period Data	1,213	75%	823	75%
Sufficient Pre- and Post- Data	755	47%	468	43%
Sufficient Pre-period Cooling	1,064	66%	636	58%
Sufficient Post-period Cooling	1,297	80%	882	81%
Flagged as Approved	1,517	94%	1,045	95%
Temperature Data	1,574	97%	1,090	100%
Total Remaining Valid Participants	719	44%	442	40%

Figure 3. Percentage of Hours with more than one missing fifteen-minute interval of runtime data in 2018-2019

The billing data processing attrition is summarized in Table 12 and Table 13 below. These tables show which sites were affected by a given screen, and how many records were removed based on that screen. The final screens for insufficient pre- and post-period data offer a rough count of the total sites or thermostats removed, as the other filters removed single records, not whole sites or thermostats. A smaller relative percent of sites (approximately 10% in both winter and summer data sets) failed to meet the billing data requirements relative to the runtime data. The fuel-type groups (gas versus electric) and Schedule Optimization groups (treatment versus control) showed similar degrees of billing data attrition.

Table 12. Billing Data Processing Attrition, at the Site level, for Winter Analysis

Screen	Fuel	Control Sites Affected*	Percent of Control Sites	Treatment Sites Affected*	Percent of Treatment Sites
Initial Electric Sites	Electric (kWh)	**896**		**1,356**	
Excluded based on Resideo account info**	Electric (kWh)	7	1%	15	1%
Program started during bill period	Electric (kWh)	873	97%	1,327	98%
Before pre-period window	Electric (kWh)	780	87%	1,153	85%
Less than 15 bill days	Electric (kWh)	18	2%	25	2%
More than 50 bill days	Electric (kWh)	862	96%	1,315	97%
Insufficient pre-period data	Electric (kWh)	75	8%	119	9%
Insufficient post-period data	Electric (kWh)	23	3%	32	2%
Remaining Electric Sites	Electric (kWh)	**797**	**89%**	**1,202**	**89%**
Initial Gas Sites	Gas (Therms)	**722**		**1,066**	
Excluded based on Resideo account info**	Gas (Therms)	6	1%	12	1%
Program started during bill period	Gas (Therms)	717	99%	1,063	100%
Before pre-period window	Gas (Therms)	618	86%	903	85%
Less than 15 bill days	Gas (Therms)	42	6%	62	6%
More than 50 bill days	Gas (Therms)	7	1%	20	2%
Insufficient pre-period data	Gas (Therms)	39	5%	63	6%
Insufficient post-period data	Gas (Therms)	8	1%	6	1%
Remaining Gas Sites After All Filters	Gas (Therms)	**674**	**93%**	**989**	**93%**

*Highlighted (dark green) cells indicate the number of sites dropped from the analysis. Sites may lose some records to each filter in light green without being removed.

**Resideo flagged sites who were removed or disqualified from the pilot but were present in their master file

Table 13. Billing Data Processing Attrition, at the Site Level, for Summer Analysis (Electric Only)

Screen	Control Sites Affected	Percent of Control Sites	Treatment Sites Affected	Percent of Treatment Sites
Initial Electric Sites	970	100%	1,455	100%
Zero consumption this bill cycle	43	4%	58	4%
Program started during bill period	44	5%	104	7%
Less than 15 bill days	32	3%	74	5%
More than 50 bill days	516	53%	773	53%
After post-period window	561	58%	838	58%
Insufficient post-period data	34	4%	51	4%
Insufficient pre-period data	60	6%	84	6%
Remaining	875	90%	1,320	91%

*Highlighted (dark green) cells indicate the number of sites dropped from the analysis. Sites may lose some records to each filter in light green without being removed.

After data cleaning, we assessed the equivalence of the Schedule Optimization groups for each system type, for both runtime and billing data. We modeled just the pre-period data using the same models as in the later billing analysis, less any terms related to the post-period (i.e. any interacted "post" terms). If either treatment or interacted treatment (e.g. with weather) terms produced significant effects ($p > 0.10$), the two groups were considered distinguishable in the pre-period and therefore not equivalent in energy use. Note that while runtime and energy use were the primary metrics of interest in this study, their equivalence in the pre-period should only be taken as a proxy for the deeper equivalence produced by randomization. In the ideal case, randomization produces equal representation across demographics, attitudes, and behaviors between Schedule Optimization groups.

As shown in Table 14, winter energy use was equivalent between Schedule Optimization groups according to our metrics for both heat pumps and gas furnaces. However, winter runtime data was not equivalent for any groups. Runtime and billing data were recorded at different frequencies, required different data cleaning considerations, and had different gaps across the study groups. A failed equivalence test is an indicator that the randomization was not perfect and indicates that a data set likely requires more than a simple difference-in-differences (DiD) calculation to determine the program effect. While this introduces more uncertainty into the causality associated with the measured effect, our use of industry-standard weather-normalizing variables reduces the severity of that concern. Given the higher frequency runtime data allows us to more confidently measure the effect, we feel that using slightly non-equivalent groups is acceptable in this case.

For the summer data, both runtime and energy use pre-period data were equivalent between groups, although summer energy use data was nearly dissimilar (p=0.08). See Figure 13 and Figure 14 in Appendix A for a graphical comparison.

Table 14. Runtime and Billing Data Equivalence

System	Runtime Equivalent?	p-value of test for similarity (Runtime)[1]	Billing Equivalent?	p-value of test for similarity (Billing)[1]
Gas Furnace	No	1e-9	Yes	0.14
Heat Pumps	No	1e-4	Yes	0.40
Electric Furnace	No	N/A[2]	No	0.03
Air Conditioning	Yes	0.8	Marginal	0.08

1 p-value shown is the lower of two p-values testing for baseline and weather-based differences between Schedule Optimization groups.

2 Electric Furnaces had insufficient pre-period data for testing similarity.

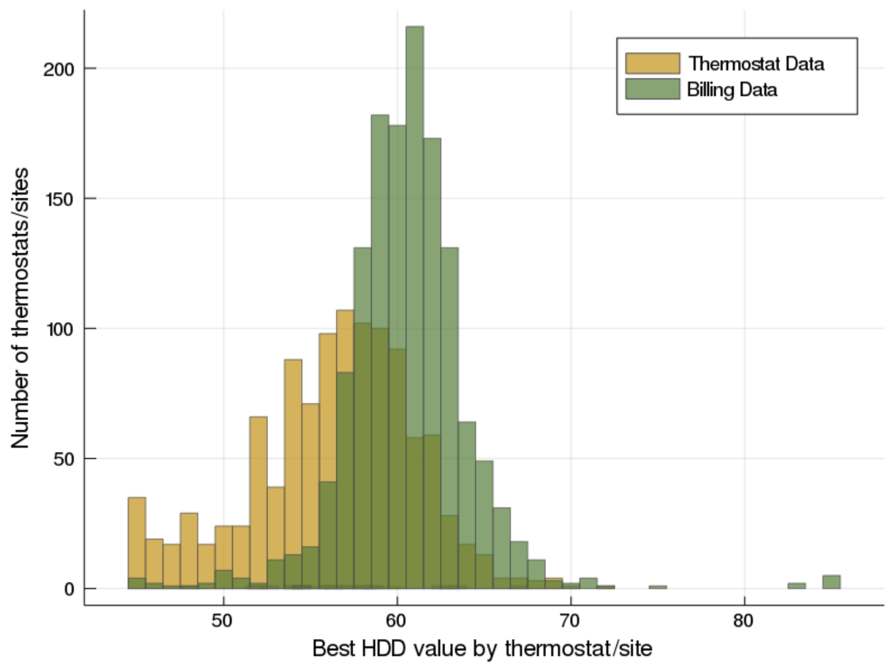
3.2 Balance Point

For both runtime and billing data sets, individual-level modeling was utilized to determine the appropriate balance point for heating degree days (HDDs) or cooling degree days (CDDs), with a variable base degree day (VBDD) approach. The panel was subset to the pre-period only[19]. Then, for each participant, we iteratively fit degree day models across all reasonable balance points (45 to 85 degrees). The balance points from the model with the lowest adjusted R^2 value were recorded for each participant. HDD and CDD for all participants in the pooled models were calculated from the average balance point determined through this method.

19 Note that balance points may change from pre- to post-period due to changes in scheduling, either through participant behavior or the model algorithm. These changes are accounted for through the "post" and "treatXpost" dummy variables in the model, which is likely an adequate but imperfect representation. The current analysis follows the prior efforts for consistency, but we note that future analyses could model pre- and post-periods independently to arrive at unique balance points for each.

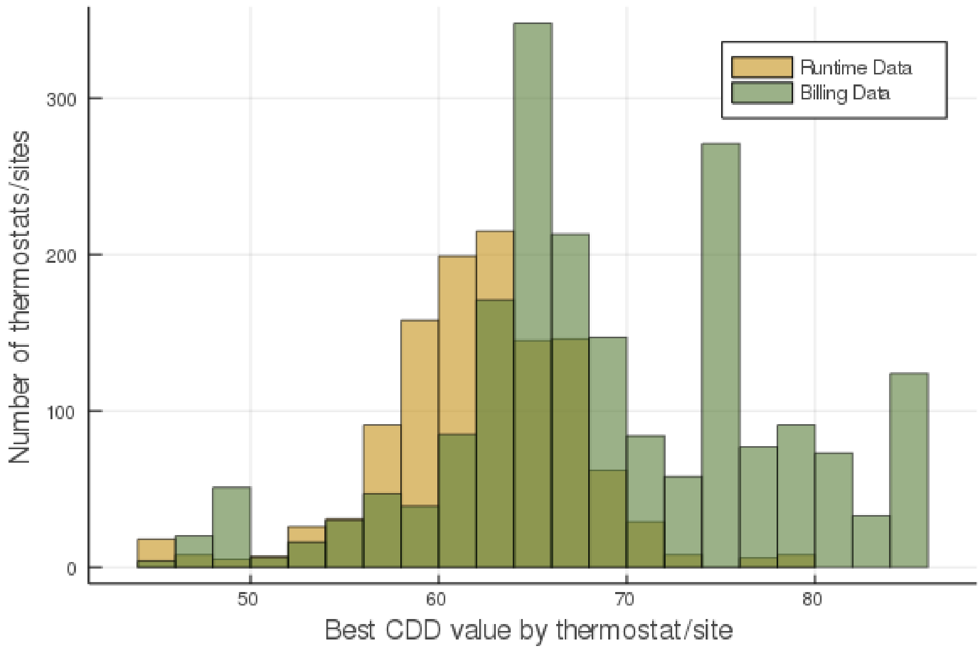
For the winter runtime data, the average HDD balance point was 57 degrees. For the winter billing data, the average balance point was 60 degrees. Figure 4 shows that difference across the population. Some discrepancy should be expected, as the thermostat data was modeled at the daily level while the billing data was modeled at the bill-period level (roughly monthly). The data points for usage per HDD were different between the two data sets. The billing-period data had less granular information at the extrema (i.e. extreme days are "smoothed" by long-running averages) and therefore tended towards a more conservative choice for balance point.

Figure 4. VBDD-Predicted HDD Balance Points for Individuals



The summer CDD balance points were similarly spread, with runtime returning a median balance point of 62 degrees and energy use returning a median balance point of 65 degrees. Once again, the differing granularity likely contributed to this difference in balance points. However, it is also notable that the billing data has a substantial population with higher balance points, suggesting intermittent or nonexistent use of cooling systems.

Figure 5. VBDD-Predicted CDD Balance Points for Individuals



4. Runtime Analysis and Findings

This section details Apex's methodological approach and key findings associated with determining the thermostat runtime savings.

4.1 Runtime Analysis Approach

The runtime analysis approach aligned with the methodology in the Seasonal Savings report as closely as possible. Whereas that report tested multiple models to determine the most appropriate method for modeling the data, we followed the established approach in this memo, deviating only where necessitated by reporting requirements.

Once the data were cleaned and tested for equivalence between Schedule Optimization groups, we modeled the effect of the program on energy consumption. Because the Connected Savings Pilot was implemented as an RCT, a DiD calculation was sufficient to determine the current-year treatment effect. To make this calculation, we created a dummy variable to designate which time points corresponded to the post-period for all participants. The interaction of "post" and "treat" terms, when properly included in a statistical model, corresponds to this DiD calculation.

We included additional terms in our runtime model for two reasons: 1) to weather-normalize the results and 2) to adjust for curtailed program intervention. For weather normalization, we modeled temperature dependence of the runtime data by interacting degree days (either CDD or HDD, denoted in the models as DD) with the other variables. This inclusion allows the model to account for overall temperature dependence, temperature dependence shifts in the post-period, temperature dependence differences between treatment and control, and temperature dependence shifts in the post period for treatment only (program effect). We account for heteroskedasticity in the model errors, but not for autocorrelation, which would have a large impact at the hourly level but is unlikely to be highly impactful at the daily level. Note that we did not include auxiliary heating from heat pumps separately in our model, despite its availability, as we mirrored the methodology from the prior report.

Using the fitted model, we then predicted the effect of treatment across a TMY. The runtime model is shown in Equation 1:

Equation 1. Initial Runtime Model

$$Runtime_{it} = \alpha_i + \beta_1(Post)_{it} + \beta_2(Treat * Post)_{it} + \beta_3(DD)_{it} + \beta_4(Treat * DD)_{it} + \beta_5(Post * DD)_{it} + \beta_6(Treat * Post * DD)_{it} + \varepsilon_{it}$$

Where:

$Runtime_{it}$	= Average daily runtime (dependent variable) for thermostat *i* during period *t.*
$Post_{it}$	= Dummy variable indicating whether period *t* was pre- or post-deployment of Connected Savings.
$Treat_{it}$	= Dummy variable indicating whether thermostat *i* is in the treatment group (1) or control group (0).
DD_{it}	= Average DDs (cooling or heating, depending on season) during period *t* at thermostat *i.*
ε	= Customer-level random error.
α_i	= Thermostat-level fixed effect for thermostat *i*, calculated separately for each home (fixed effect). Average daily non-weather dependent usage in the pre-deployment period.
β_1	= Coefficient representing the change in daily base runtime in the post period for the control group.
β_2	= Coefficient representing the change in daily base runtime in the post period for the treatment group net of any change observed in the control group.
β_3	= Coefficient representing the average daily runtime per HDD/CDD in the pre-deployment period for the control group.
β_4	= Coefficient representing the average daily runtime per HDD/CDD in the pre-deployment period for the treatment group, net the runtime of the control group.
β_5	= Coefficient representing the change in average daily runtime per HDD/CDD in the post-deployment period for the control group.
β_6	= Coefficient representing the change in average daily runtime per HDD/CDD in the post-deployment period for the treatment group net of any change observed in the control group.

We made a second adjustment, in the heating season only, to account for the PGE DR and Connected Savings interaction issues. As noted above, after the first winter PGE DR event on February 14th, Resideo discovered that an interaction between the schedule optimization for energy efficiency and the demand response algorithms was driving down temperatures excessively in participant homes with ecobee thermostats. The Resideo team was unable to rectify the issue during the winter and opted to curtail schedule optimization for those homes. As ecobee thermostats made up roughly two-thirds of participant devices, program savings fell off dramatically by removing them from the pool. To account for this issue separately from the savings while the schedule optimization was working correctly, we added an additional interacted term to model the effect of this "gap" period. The interaction terms were important to control for time-dependent changes in consumption for the control group of ecobee thermostats, unrelated to the issue with the algorithm. The adjusted model is shown in Equation 2:

Equation 2. Adjusted (Final) Runtime Model

$$\begin{aligned} Runtime_{it} = \alpha_i + \beta_1(Post)_{it} + \beta_2(Treat*Post)_{it} + \beta_3(HDD)_{it} + \beta_4(Treat*HDD)_{it} \\ + \beta_5(Post*HDD)_{it} + \beta_6(Treat*Post*HDD)_{it} \\ + \beta_7(Gap)_{it} + \beta_8(Treat*Gap)_{it} + \beta_9(Gap*HDD)_{it} + \beta_{10}(Treat*Gap*HDD)_{it} \\ + \varepsilon_{it} \end{aligned}$$

Where:

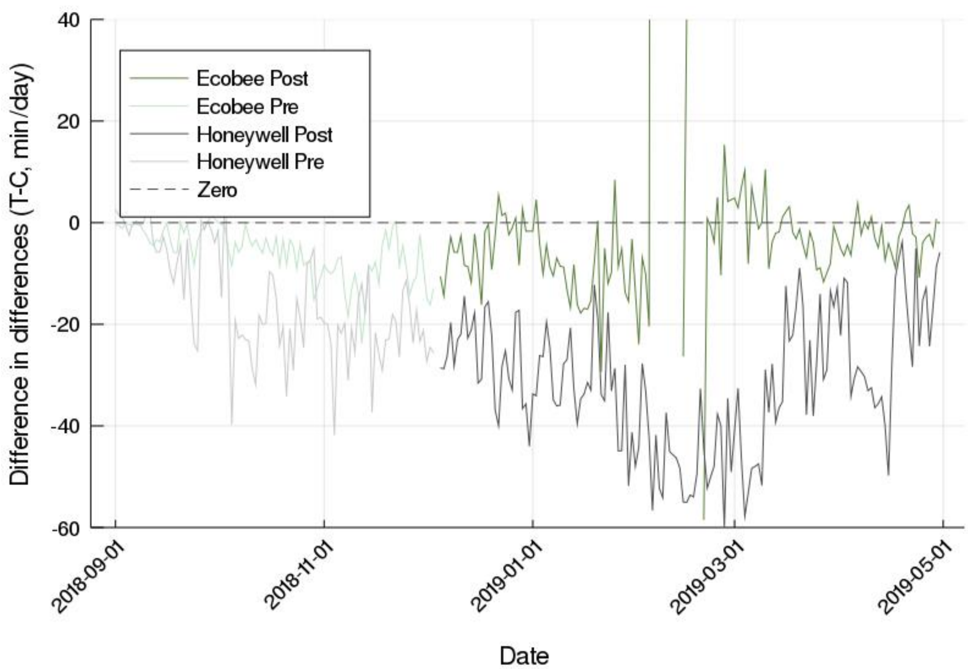
Gap_{it}	= Dummy variable indicating whether period t was after February 14th and thermostat i was an ecobee.
β_7	= Coefficient representing the change in daily base runtime in the gap period for the ecobee control group.
β_8	= Coefficient representing the change in daily base runtime in the gap period for the ecobee treatment group net, of any change observed in the ecobee control group.
β_9	= Coefficient representing the change in average daily runtime per HDD in the gap period for the ecobee control group.
β_{10}	= Coefficient representing the change in average daily runtime per HDD in the gap period for the ecobee treatment group, net of any change observed in the ecobee control group.

From our winter runtime analysis, we report two savings estimates. The first is the naive estimate, incorporating no information about the algorithmic issues (i.e., not correcting for the curtailment in schedule optimization that occurred after February 14th). The second is adjusted for the schedule optimization curtailment, estimating what savings would have been if the issue had not occurred. Resideo has reported that the issue persisted throughout the whole summer, and therefore we do not provide a similar breakout for the cooling results.

4.2 Winter Runtime Analysis Findings

Apex found statistically significant runtime changes for thermostats connected to natural gas furnaces and heat pumps, but not for electric furnaces. Figure 6 shows the DiD runtime differences in the pre- and post-period, by brand. Table 16 shows the results of this analysis, with estimated runtime reductions in the post-period and the final column corresponding to predicted runtime reduction in a typical (weather normalized) year. According to the telemetry analysis, furnaces and heat pumps both reduced runtime in the post-period. Furnaces reduced total runtime by 6.7%±3.2%, or 6.6% without adjustment. Heat pumps reduced total runtime by 6.0%±4.7%, or 5.8% without adjustment.

Figure 6. Resideo Winter Connected Savings Runtime Differences – Treatment versus Control



Note: The program started across 45 days for different participants, but we group this chart by the average start date.

As shown earlier in Section 3.1, Data Cleaning and Validation, the electric furnace group started with a small number of participants and lost half of them through data cleaning (see Table 15 below). Therefore, it is unsurprising that runtime savings for that group were not measurable. However, given that electric and gas furnaces operate similarly, Apex recommends that the gas furnace results be applied to electric furnaces, adjusted for efficiency and converted to kWh.

Table 15. Number of Treatment and Control Thermostats in Runtime Analysis after Cleaning

Group	Treatment Thermostats in Model	Control Thermostats in Model
Gas Furnace	715	462
Heat Pump	351	211
Electric Furnace	7	6

Table 16. Winter Runtime Analysis Results, Thermostat Level

Group	Baseline runtime Hours (Winter 2018-2019)	Treatment Effect (hours/ year)	Weather Normalized (TMY) Treatment Effect (hours/year)	TMY 90% CI (hours/ year)	Relative Precision at 90% Conf.	% Savings (Weather-Normalized)
Gas Furnace	454	-30.5	-37.2	±17.9	48%	6.7%
Heat Pump	646	-38.9	-50.0	±39.6	79%	6.0%
Electric Furnace	395	-26.7**	-38.4	±250.3	652%	6.8%

* CI–Confidence interval.

** Estimates for baseline runtime and savings for Electric Furnace were not significant (p>0.25) due to low sample size.

4.1 Summer Runtime Analysis Findings

Apex found statistically significant savings from analysis of the runtime data for the 2019 summer. Table 17 shows the counts available for the summer analysis by analysis group. Table 18 shows the results of this analysis, with estimated runtime reductions in the post-period and the final column corresponding to predicted runtime reduction in a typical (weather-normalized) year. According to the telemetry analysis, air conditioners reduced total runtime for a typical year by 4.0%±3.2%. It should be noted that the summer electric savings are for all systems with AC (inclusive of AC + Gas Furnace and heat pump systems).

Table 17. Number of Treatment and Control Thermostats in Summer Runtime Analysis after Cleaning

Group	Treatment Thermostats in Model	Control Thermostats in Model
Air Conditioning	720	442

Table 18. Summer Runtime Analysis Results for Air Conditioners, Thermostat Level

Baseline runtime Hours (Summer 2019)	Treatment Effect (hours/ year)	Weather Normalized (TMY) Treatment Effect (hours/year)	TMY 90% CI (hours/year)	Relative Precision at 90% Conf.	% Savings (Weather-Normalized)
372	-14.7	-14.2	±11.8	±83%	4.0%

Figure 7 shows the DiD runtime differences in the pre- and post-period, by brand. In that figure, both Honeywell and ecobee thermostats appear to save a modest amount, although the ecobee savings are concentrated in July and early August while the Honeywell savings are spread throughout. Given the high levels of data loss, we do not recommend drawing a conclusion directly from this DiD graph.

Figure 7. Resideo Summer Connected Savings Runtime Differences – Treatment versus Control

5. Billing Analysis and Findings

This section details Apex Analytics approach to determining the thermostat savings from an analysis of electric and gas billing data.

5.1 Winter Billing Analysis Approach

Although data cleaning between the two data sets differed slightly, the billing analysis followed a similar approach to the runtime analysis. We leveraged the DiD design of the experiment and included terms for weather normalization. As discussed in the **Runtime Analysis Approach** section, we included a "gap" term to estimate savings in the absence of schedule optimization curtailment (i.e., as if schedule optimization had extended through the entire heating season). The model was run on billing periods, not days, but all variables were normalized to the average daily level.

The only notable addition to the billing models was a term for cooling degree days in the winter model. In the runtime models, cooling minutes and heating minutes were recorded separately, and their outcomes were independent of each other. In the electric billing data, cooling and heating both contributed to consumption, but the winter schedule optimization only affected heating usage. Therefore, to model the seasonal heating usage, effects of cooling must be controlled for. The cooling degree day (CDD) term accounts for (a small amount of) cooling energy use and, to a lesser extent in the natural gas model, the diminished energy consumption of water heaters in summer. The billing analysis models do not adjust for autocorrelation beyond the calculation of errors that are robust to heteroskedasticity. The full model used is shown in Equation 3.

Equation 3. Billing Analysis Model

$$\begin{aligned} Energy_{it} = \alpha_i &+ \beta_1(Post)_{it} + \beta_2(Treat * Post)_{it} + \beta_3(HDD)_{it} + \beta_4(Treat * HDD)_{it} \\ &+ \beta_5(Post * HDD)_{it} + \beta_6(Treat * Post * HDD)_{it} \\ &+ \beta_7(Gap)_{it} + \beta_8(Treat * Gap)_{it} + \beta_9(Gap * HDD)_{it} \\ &+ \beta_{10}(Treat * Gap * HDD)_{it} + \beta_{11}(CDD)_{it} + \varepsilon_{it} \end{aligned}$$

Where:

$Energy_{it}$	= Average daily energy consumption (kWh or therms) for home *i* during billing period *t*.
$(CDD)_{it}$	= Average daily CDDs during billing period *t* at home *i*.

5.2 Winter Billing Analysis Findings

Billing analyses found statistically significant natural gas savings for gas furnaces. While the savings point estimates were positive for heat pumps and for furnace fans, supporting the results of runtime analysis, they were not statistically significant. As a reference, we include the total numbers of sites included in each model across the HVAC system types in Table 19 below. For gas furnaces, point estimates for savings were below the estimates from runtime analysis (2.5% vs. 6.7%). For heat pumps, point estimates for savings were not statistically significant, and were also below the estimates from runtime analysis (1.0% vs. 6.0%). The unadjusted estimates were lower still, at 1.8% for gas furnaces and 0.0% for heat pumps. We discuss these discrepancies in Section 6. Table 20 shows the savings results at the home level for all system types in the schedule optimization pilot, along with estimates for a typical (weather normalized) year. For electric furnaces, we converted the total use, savings, and error for gas furnaces into kWh using an assumed gas furnace efficiency of 87%, given that the systems operate in a similar fashion.

Table 19. Number of Treatment and Control Sites in Billing Analysis after Cleaning

Group	Treatment Sites in Model	Control Sites in Model
Gas Furnace (therms)	546	825
Furnace Fan (kWh)	569	849
Heat Pump (kWh)	241	362
Electric Furnace (kWh)	10	15

Table 20. Winter Billing Analysis Results, Site Level

System Type	Units	Total Use in Post Period (2018/ 2019 Winter)	Estimated Post-Period Effect	Estimated Weather-Normalized (TMY) Effect	TMY 90% CI	Relative Precision at 90% Conf.	% of Heating Use (Weather-Normalized)
Gas Furnace	therms	313	-8.0	-12.8	±8.3	65%	2.5%
Furnace Fan	kwh	591	-26.7	-44.6	±399.9	897%	5.1%

System Type	Units	Total Use in Post Period (2018/ 2019 Winter)	Estimated Post-Period Effect	Estimated Weather-Normalized (TMY) Effect	TMY 90% CI	Relative Precision at 90% Conf.	% of Heating Use (Weather-Normalized)
Heat Pump	kwh	2,657	-30.2	-48.3	±121.0	251%	1.0%
Electric Furnace*	kwh	7,984	-202.7	-326.3	±211.9	65%	2.5%

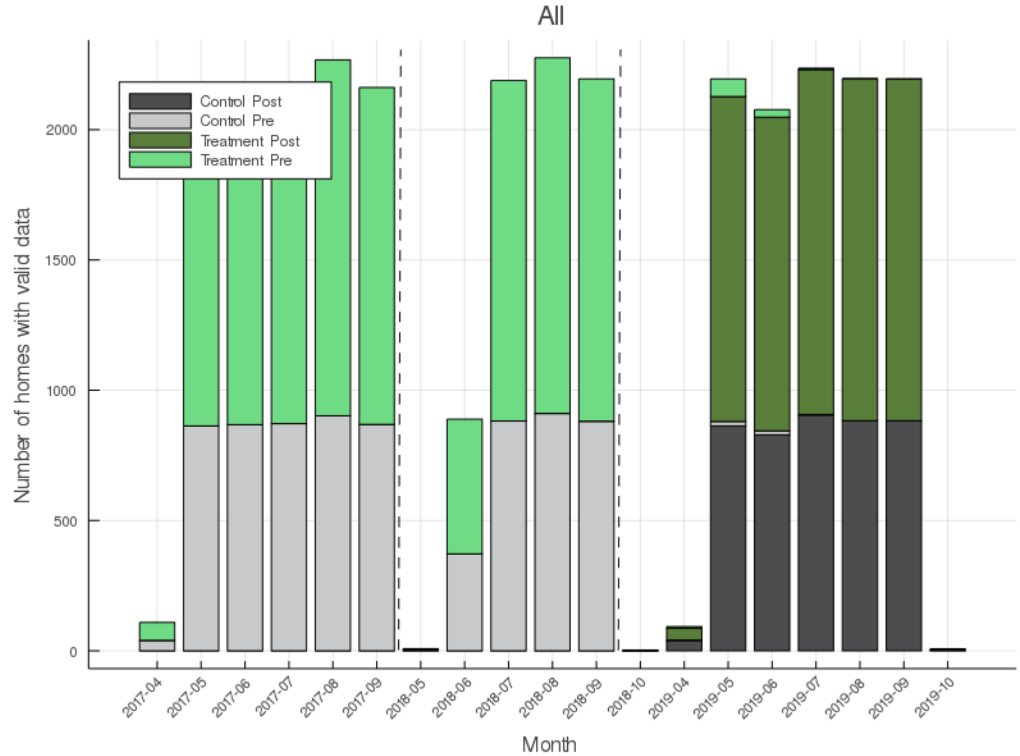
* Electric Furnace values calculated using Gas Furnace values converted to therms.

5.1 Summer Billing Analysis Approach

Given that there were two summers (2017 and 2018) of pre-period billing data available, and that the treatment groups could be combined into one group with air conditioning[20], the summer billing analysis had sufficient pre-period data to conduct a summer-only (May through September) analysis. The average included site had 8.5 bills from the pre-period and 5 bills in the post-period. Figure 8 shows the number of homes with valid data for summer analysis by month in the pre- and post-periods. Note that a small number of homes did not begin treatment until the middle of the 2019 summer, as shown in the Figure. The models employed in this analysis mirrored the summer runtime analysis models.

20 As a reminder, summer savings is defined as any home with air conditioning, including those with AC + Gas Furnace and those with heat pumps.

Figure 8. Number of homes with valid data for summer analysis by month in the pre- and post-periods



5.2 Summer Billing Analysis Findings

Point estimates from billing analyses indicate savings for air conditioners, but these estimates were not statistically significant (p=0.22). These point estimates were higher than the percent savings estimates from runtime analysis (7% vs. 4%), despite having wider confidence intervals. The confidence intervals from both analyses overlap, suggesting agreement. As a reference, Table 21 shows the total sites available for the model by analysis group. Table 22 shows the savings results at the home level, along with estimates for a typical (weather normalized) year. Figure 9 shows the DiD values between treatment and control groups for 2017, 2018, and 2019 for both brands. According to the billing data, ecobee saves a modest amount in July (as seen in the runtime DiD), while Honeywell saves substantially more throughout.

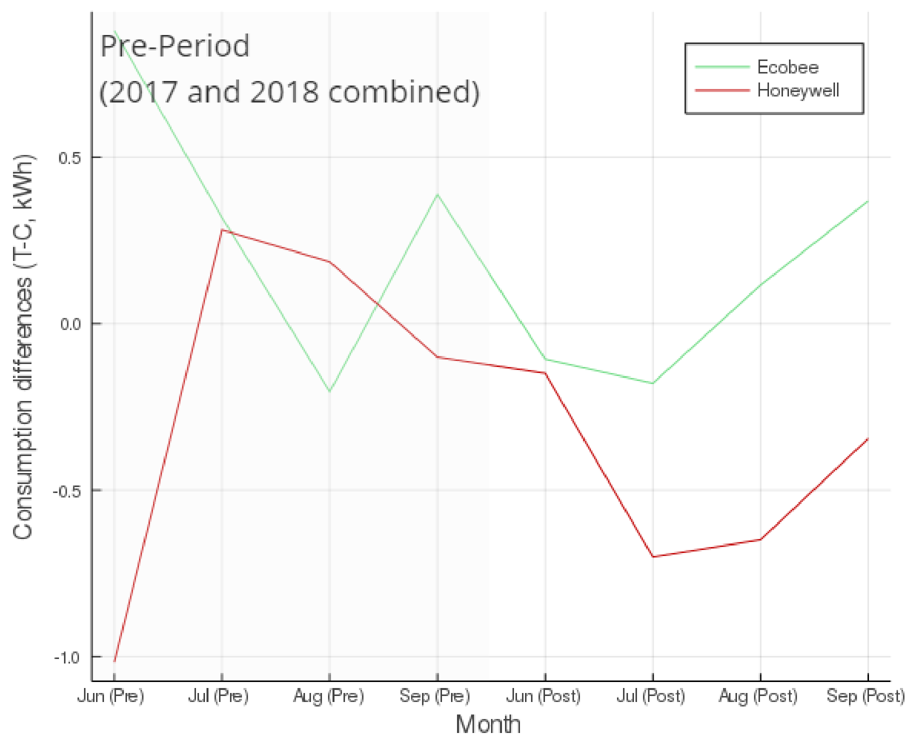
Table 21. Number of Treatment and Control Sites in Summer Billing Analysis after Cleaning

Group	Treatment Sites in Model	Control Sites in Model
Air Conditioning	1320	875

Table 22. Summer Billing Analysis Results, Site Level

Cooling Use in Post Period (kWh, Summer 2019)	Estimated Post-Period Effect (kWh)	Estimated Weather-Normalized (TMY) Effect (kWh)	TMY 90% CI	Relative Precision	% of Cooling Use (Weather Normalized)
837	-58.6	-31.6	±46.3	147%	7.0%

Figure 9. Resideo Summer Connected Savings Energy Consumption Differences – Treatment versus Control



6. Combined Analysis Findings

The analysis and findings described above separately discussed the results of runtime and billing models. The advantage of having both estimates is that it allows us to estimate the average HVAC equipment size – or capacity. The capacity is an important estimated metric for the Pilot because it is used to convert runtime measurements captured by the Resideo schedule optimization service to kWh savings. The Apex team combined the billing and runtime analyses to estimate updated system capacity values for the heating and cooling systems in the pilot. The modeling results of billing analysis separated out heating consumption and other energy consumption, providing an estimate for energy consumed for heating. Summary statistics of the thermostat data include number of devices per home and hours of total runtime. With some efficiency assumptions, these results can be input into an engineering equation to estimate average system sizes (energy input per hour), as shown in Table 23. The equations to generate the system capacities are:

$$Gas\ Furnace\ Input\ Capacity = \frac{Est.Heating\ Use\ (therms)}{Runtime\ Hours} \times \frac{kBTU}{therm}$$

$$Electric\ Fan\ Capacity = \frac{Est.Heating\ Use\ (kWh)}{Runtime\ Hours}$$

$$Heat\ Pump\ Output\ Capacity = \frac{Est.Heating\ Use\ (kWh)}{Runtime\ Hours} \times \frac{3.412}{HSPF} \times \frac{kBTU}{kWh} \times \frac{tons}{kBTU/_{hour}}$$

$$Electric\ Furnace\ Input\ Capacity = \frac{Est.G.F.Heating\ Use\ (therms)}{Gas\ Runtime\ Hours} \times \frac{Gas\ Eff.}{Electric\ Eff.} \times \frac{kBTU}{therm}$$

$$Air\ Conditioner\ Capacity = \frac{Est.Cooling\ Use\ (kWh)}{Runtime\ Hours} \times \frac{1\ \text{kBTU/hour}}{EER} \times \frac{12\ tons}{kBTU/_{hour}}$$

Our capacity estimates for gas furnaces and heat pumps largely agree with the prior estimates developed during the Nest Seasonal Savings Pilot, but our estimates for air conditioner and furnace fan consumption differed significantly. It is possible that, within the gas furnace group, there are homes with electric back-up (e.g. strip heat) or supplemental electric space heaters, and these units register as electric heating use in our models. For air conditioners, the energy use model likely allocates less usage to cooling (CDD term) than is truly being consumed, because customer behaviors decouple cooling use directly from weather. While the final savings values (≈32 kWh) are not affected by this because savings are also quantified by the *post*treat* (weather independent) term, we believe that the quantification of AC size below is an underestimate. The AC size estimate is based off of the assumption that AC electric use is represented by the weather-dependent terms in the model during the cooling season - a decoupling of use from weather will show up in the model as baseline usage, thereby underestimating the electric use attributable to the AC (and underestimating its size). Table 23 shows the calculation of total system capacity at the site level, while Table 24 converts that calculation into per-thermostat estimates for use in estimating the future impacts by number of enrolled thermostats. The confidence intervals in these estimates are based on the 90% confidence interval of the estimated heating or cooling energy use extracted from the models, but those intervals do not account for bias in the sample, if it exists.

Table 23. Estimated Capacity per Home by System Type

System	Units	Runtime Hours	Estimated Heating Energy Use (Post)	Assumed Efficiency[21]	Capacity**
Gas Furnace	therms	454	313	87%	69±4 kBTUh
Furnace Fan	kWh	454	591	100%	1.3±0.3 kW
Heat Pump	kWh	646	2657	264%	3.1±0.5 tons
Electric Furnace*	kWh	454	7,984	100%	60±3 kBTUh
Cooling System	**Units**	**Runtime Hours**	**Estimated Cooling Energy Use (Post)**	**Efficiency (EER)**	**Capacity**
Air Conditioner	kWh	372	837	10.7	2.0±0.3 tons

* Electric Furnace values calculated using Gas Furnace values converted to therms.

**Capacities reported in units corresponding to standard industry terminology (e.g. tonnage for heat pumps, input capacity for furnaces).

For the preceding estimates, we calculated the site-level capacity, not an assumed capacity per furnace/AC. In the table below we incorporate the number of thermostats per home to arrive at thermostat-level consumption estimates. Note that it is possible that two thermostats control a single system (e.g. for zonal systems), so these are not true “per system” estimates.

[21] Efficiencies using Oregon data from the “Residential Building Stock Assessment II: Single Family Homes Report,” 2016-2017. For heat pumps, HSPF = 8.3 and efficiency is relative to resistance heat where HSPF = 3.4. For ACs, EER = 10.7, the most likely EER associated with a SEER=12.2 AC.

Table 24. Energy Consumption per Thermostat Calculations

System	Capacity	Thermostats per Home	System Capacity per Thermostat (size units)	Prior Capacity Estimate[22]	System Capacity per Thermostat (energy units)
Gas Furnace	69 kBTUh	1.035	66.6±3.6 kBTUh	65 kBTUh	0.67±0.04 therms/hr
Furnace Fan	1.3 kW	1.035	N/A	0.56 kW	1.26±0.34 kW
Heat Pump	3.1 tons	1.035	3.0±0.5 tons	3 tons	3.97±0.67 kW
Electric Furnace*	60 kBTUh	1.035	58.0±3.1 kBTUh	-	16.99±0.91 kW
Air Conditioner	2.0 tons	1.024	1.96±0.23 tons	2.9 tons	2.20±0.26 kW

* Electric Furnace values calculated using Gas Furnace values converted to therms.

Using the system capacity estimates in Table 24, we can convert from runtime savings per thermostat to energy savings. Table 25 shows the capacity assumptions and the resulting weather normalized energy savings results per thermostat.

Table 25. Conversion of Runtime Results to Energy Savings

System	Capacity Assumption (per thermostat)	Fuel units	TMY Savings	TMY Effect 90% CI	Relative Precision
Gas Furnace	66.6 kBTU/hr	therms	-25	±12	±48%
Gas Furnace Fan	1.26 kW	kWh	-47	±23	±48%
Heat Pump	3.97 kW	kWh	-199	±158	±79%
Electric Furnace	17.0 kW	kWh	-652	*	*
Air Conditioner	2.2 kW	kWh	-31	±26	±84%

* CIs not reported because effect is a derived value.

22 Apex Analytics and Demand Side Analytics, "Energy Trust of Oregon Nest Thermostat Seasonal Savings Pilot Evaluation," prepared for Energy Trust of Oregon (November 2017).

The estimates from runtime and billing analysis differ substantially in the winter season. There are several potential reasons for the differences that we were unable to ascertain from the study design. Potential reasons include:

- Potential secondary systems and seasonal use in the billing data baseline, such as from water heaters in unconditioned spaces, auxiliary heating (e.g. gas fireplaces), and space heaters.
- Unknown correlation between thermostat data issues and connectivity issues, with the potential for lost runtime data to signify a loss of schedule optimization function.
- Outside cases where thermostats control only a portion of the home's HVAC use, or the thermostats are moved after program start.
- Bias in the system capacity estimates due to behavioral effects will affect the predicted energy savings from runtime analysis.

For furnace fans and heat pumps, the wide confidence intervals (CIs) on billing analysis savings results suggest that runtime-based estimates should be preferred, but we acknowledge that there is likely more bias in the runtime-based estimates. However, width of the CIs on the therm savings results for gas furnaces were similar between runtime and billing analyses but the savings estimates differed by a factor of two.

Due to filtering during data cleaning, the customers that were included in the runtime model and the billing model were not the same. To combine the estimates from runtime and billing analysis, we first assessed whether modeling using the same set of customers in both groups produced different estimates for savings. As this exclusive group was smaller than either the group previously included in the runtime analysis or the group previously included in the billing analysis, CIs for both analyses increased. Figure 10 and Figure 11 show the results of applying this "double filter" on the modeled savings. Although the changes were small, point estimates of savings for the billing analysis increased and estimates of savings for the runtime analysis decreased. In other words, the two estimates got closer together. However, this double filter also caused the billing analysis Schedule Optimization groups to become less equivalent for both furnaces and heat pumps.

Figure 11, also shows the "gas participants" results for Furnace Fan savings estimates. In that round of winter electric billing analysis, we excluded participants from the "AC + Furnace" group who did not also have gas data and found savings results that were lower by 58% compared to electric billing analysis without that filter. This result could be interpreted to mean that some participants were mischaracterized as having gas furnaces when they had electric furnaces, drastically increasing the savings results assumed to derive from the electric fan (and therefore the estimated electric fan consumption). The results of this modified "gas participants only" analysis was used by the Apex team for all furnace fan savings and sizing estimates.

Figure 10. Winter Natural Gas Savings Estimates by Level of Filtering and Data Set

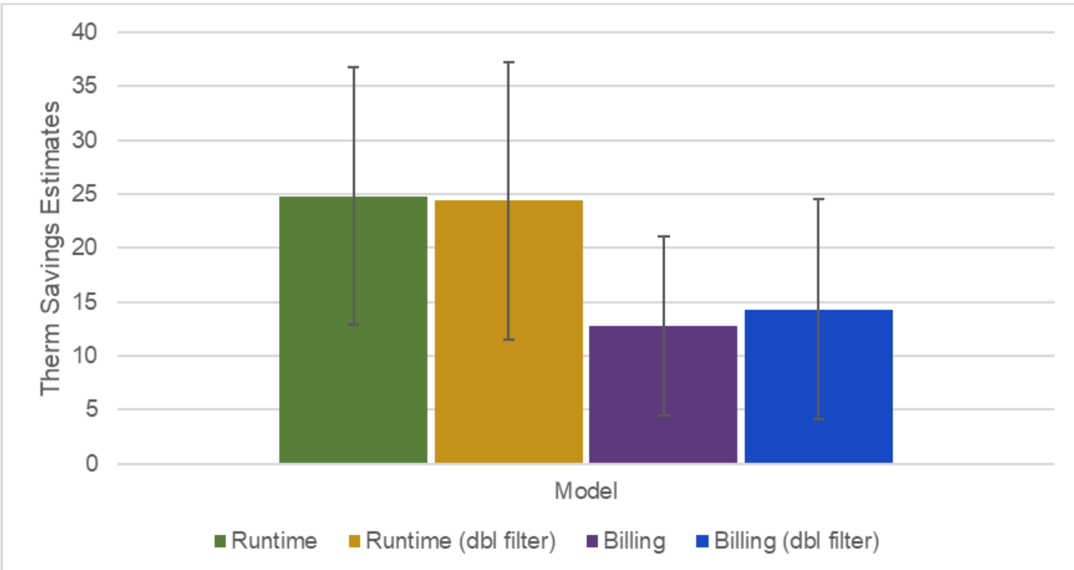
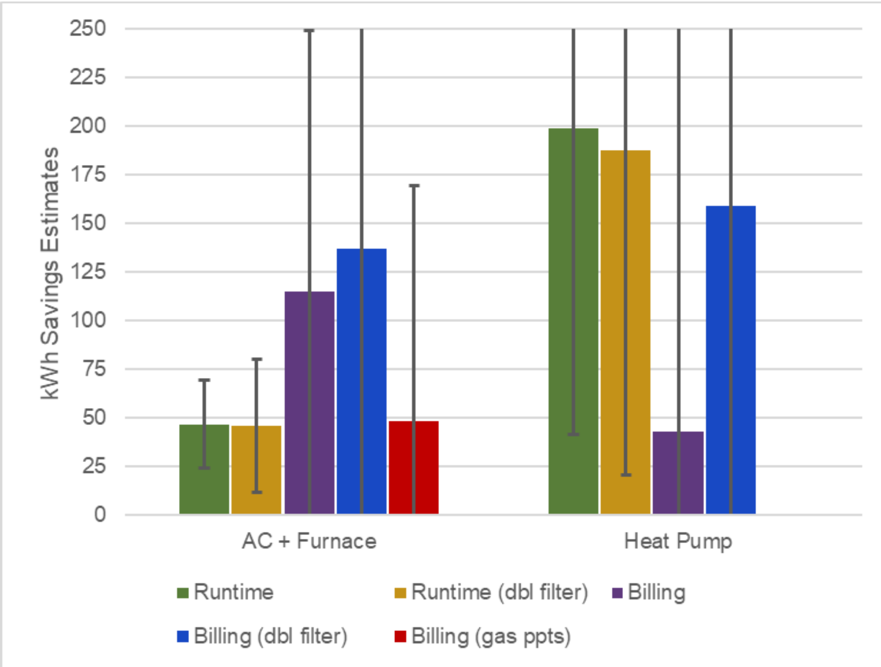


Figure 11. Winter Electric Savings Estimates by System, Level of Filtering, and Data Set



"Gas ppts" refers to an analysis of electric billing data using only those participants who also have gas data, to confirm that furnace fan savings are truly associated with gas furnaces.

In order to combine the two estimates to reach a final savings estimate, we assumed the estimates were independent and weighted them to minimize the standard error, according to the methodology in "Combining Estimates," by Thomas Struppeck.[23] That calculation reduces to a formula for the weighting ratio of:

$$r_{bill/rt} = \frac{{SE_{rt}}^2}{{SE_{rt}}^2 + {SE_{bill}}^2}$$

We calculated this weighting ratio for each of the system types in the study and used the ratio to combine savings estimates. While the standard error on natural gas savings estimates was lower from billing analysis, the runtime analysis produced tighter standard errors for the electric savings estimates. Note that we opted not to use the "double filtered" results for combination, as they had wider CIs than their counterparts and introduced additional bias into the billing analysis sample. Table 26 shows the final estimates for natural gas and electricity savings due to the Connected Savings schedule optimization. The savings were positive and

23 https://www.casact.org/pubs/forum/14sumforumv2/Struppeck.pdf

significant up to the 99.5% confidence level for gas furnaces and their fans, as well as heat pumps. For electric furnaces, the sample was too small to estimate savings, but savings can be assumed from extrapolation of the natural gas savings results.

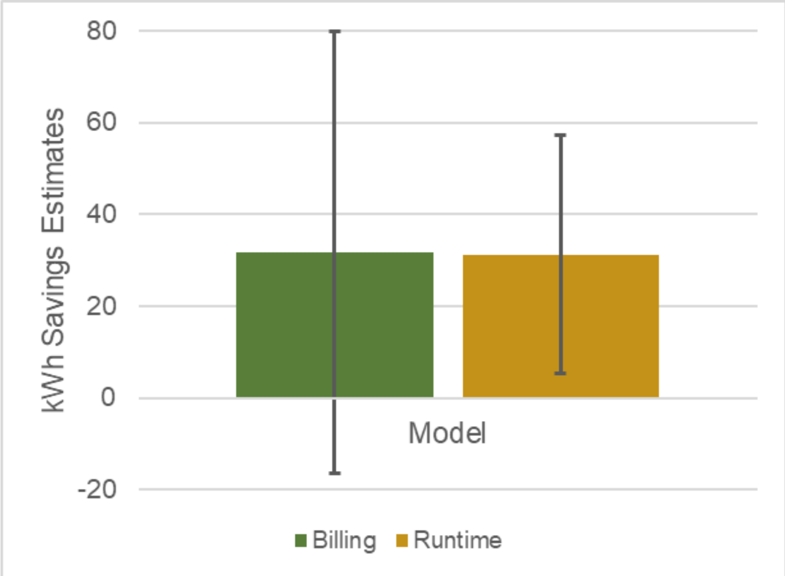
Table 26. Combined Per-Thermostat Energy Savings for the Resideo Connected Savings Pilot, by System and Fuel Type

System	Units	Combo Ratio (Billing/Runtime)	TMY Savings	TMY 90% CI	Relative Precision at 90% Conf.	TMY Heating/Cooling Savings (%)
Gas Furnace	Therms	68.8%	16	±7	44%	3.2%
Furnace Fan	kWh	2.7%	49	±22	45%	5.1%
Heat Pump	kWh	14.2%	177	±146	82%	4.0%
Electric Furnace*	kWh	-	414	±170	41%	3.2%
Air Conditioner	kWh	-	31	±26	84%	3.9%

* Electric Furnace values calculated using Gas Furnace values converted to therms.

For the summer, the TMY savings estimates from runtime and billing analysis align closely (±1 kWh), Figure 12. Therefore, we use the higher precision estimate (runtime analysis) and avoid the complex combination scheme. We also believe that the runtime analysis more accurately assigns cooling load (due to intermittent cooling use discussed above), so the cooling percentage from runtime analysis is also preferable.

Figure 12. Summer Electricity Savings Estimates by Data Set



7. Conclusions and Recommendations

The Resideo Connected Savings service offers thermostat schedule optimization for energy efficiency on a broader range of thermostats than the Nest Seasonal Savings service. The Resideo service also offers a different approach to energy savings relative to Nest. The Connected Saving Pilot was easily implemented by piggybacking off of the PGE DR Pilot. Because of these features, Energy Trust sought to engage with the Resideo service and offer the Connected Saving Pilot to customers already enrolled in the PGE DR Pilot. Based on a holistic view of the pilot from our research, which included conversations with Resideo and Energy Trust staff, analysis of thermostat runtime, and billing analysis, we offer the following key conclusions and recommendations.

Conclusion 1: The promise—and benefits—of an expanded schedule optimization service across multiple thermostat vendors was offset by data connectivity and functionality issues. In particular, the PGE DR service conflicted with the Energy Trust schedule optimization service, while the ecobee API experienced disruptions to connectivity and suffered interim data loss. *Having a thermostat efficiency service that works across multiple vendors and does not require advanced smart thermostat functionality is highly appealing, particularly to broaden the available base of thermostats and to leverage DR simultaneously. However, the Connected Savings service struggled somewhat with compatibility and reliability. Resideo was able to address many of the data issues, yet the final runtime data suffered high levels of data loss during the high-heating load month of February and the experimental design was slightly compromised in the month of August.*

Recommendation 1: *Future multipurpose solutions to thermostat-controlled DR and thermostat schedule optimization should be vetted to ensure that both services can be delivered seamlessly without one impacting the other.*

Conclusion 2: The Resideo Connected Savings service impact on participants' home comfort levels is uncertain. *The* ***Connected Savings*** *Pilot experienced low levels of opt-out and disconnection rates, comparable with the Nest Seasonal Savings Pilot. Approximately 5% of winter participants and 4% of summer participants either opted out or disconnected their devices during the treatment periods. Yet, for the small group of participants who dropped out of the* ***Connected Savings*** *Pilot, changes to home comfort or concerns about the potential for changes to comfort were the driving factors. Because there was no participant survey to gauge* *feedback on home comfort levels during the Pilot, we cannot qualify the participant experience. To infer changes to home comfort due to a comparable program offering, the Seasonal Savings Pilot showed moderate impacts to participant-reported changes to home comfort, with some participants noting that the services made their homes less comfortable.*

Recommendation 2: *While it is appropriate to consider the qualitative findings on comfort from the Seasonal Savings Pilot as a proxy for the Connected Savings Pilot, Energy Trust should consider a survey similar to the one conducted for the Seasonal Savings Evaluation to assess home comfort and satisfaction with the Pilot.*

Conclusion 3: The Resideo Connected Savings Winter and Summer service provided significant gas and electric savings, at similar levels relative to the Nest Seasonal Savings service. The precision of the winter savings estimate was lower for heat pumps (82% at 90% confidence) than for natural gas furnaces (44% at 90% confidence). *Our combined runtime and billing analyses found reductions of 3.2% primary heating fuel savings and 5.1% fan electric savings for thermostats connected to furnaces. For heat pumps, we found reductions of 4.0% of heating electric use, but did not independently analyze whether Connected Savings caused a change in auxiliary heating use.*

Recommendation 3: *Energy Trust should adopt the per-thermostat savings values shown in Table 1 for future Connected Savings schedule optimization programs. If Connected Savings is expanded into a larger program, Energy Trust could use a similar design to this study for heat pumps only to revisit auxiliary heating use and the precision of the savings estimate.*

Conclusion 4: The Resideo Connected Savings Summer service provided significant electric savings, higher than the Nest service. The precision of the savings estimate was low (80% at 90% confidence) but still significant. *Our combined runtime and billing analyses found reductions of 3.9% savings for central air conditioning systems.*

Recommendation 4: *Energy Trust should adopt the per-thermostat savings values shown in Table 1 for future Connected Savings schedule optimization programs.*

8. Appendices

8.1 Appendix A

Figure 13. Summer Runtime Equivalence Check

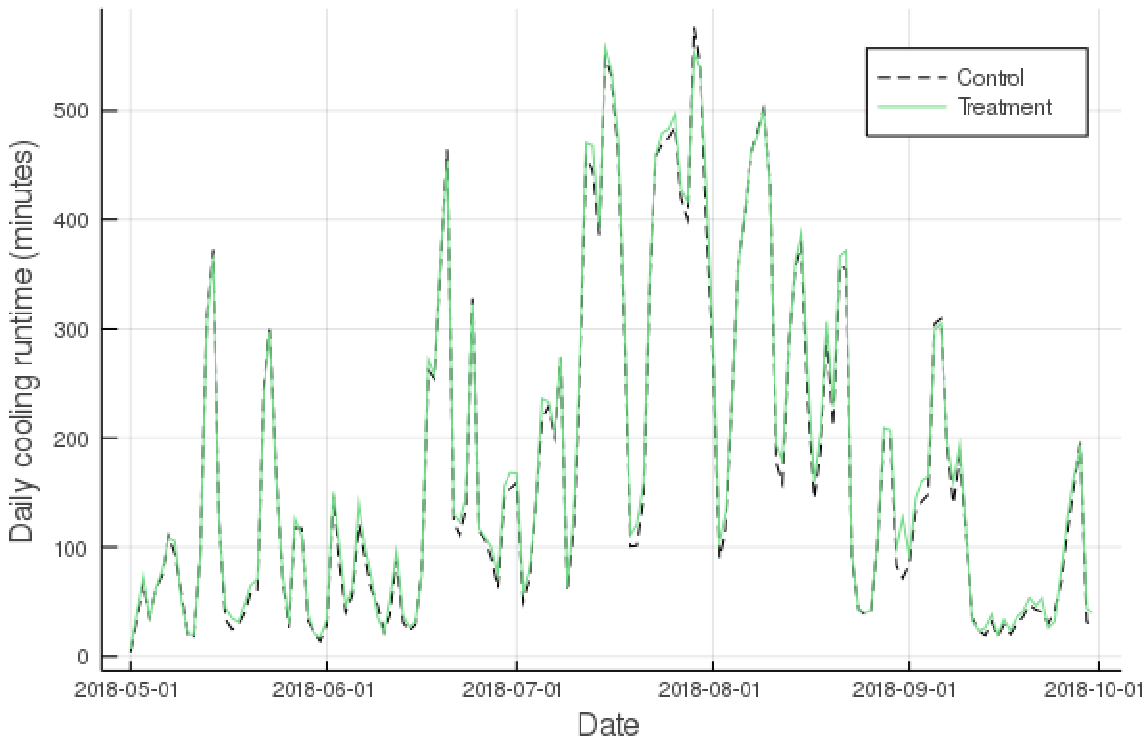


Figure 14. Summer Energy Use Equivalence Check