2018-2019 MASSACHUSETTS WINTER THERMOSTAT OPTIMIZATION EVALUATION

Prepared for:
The Program Administrators of Massachusetts

Submitted by:
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STUDY OVERVIEW

About Thermostat Optimization

The Winter Seasonal Savings (SS) program is a thermostat optimization program offered by Google designed to make incremental adjustments to scheduled setpoints over a 3-4-week period to achieve energy savings and demand reductions during the winter while maintaining customer comfort. On average, scheduled setpoints are adjusted downwards by 0.5°F-1.5°F during the heating season, with the largest temperature adjustments taking place when customers are typically asleep (i.e., late evening through early morning).

Study Goal

The goal of the thermostat optimization evaluation was to confirm the technical feasibility of using thermostat setpoint adjustments to reduce household energy consumption and peak demand. The evaluation included both an exploratory analysis of thermostat setpoints and an impact analysis of energy and demand savings.

The evaluation also yielded realization rates, providing the PAs with a point of comparison between the evaluated savings and the vendor-generated savings.

APPROACH

The evaluation team relied on two analyses for the 2018-2019 evaluation:

Exploratory Analysis

- Assessed program eligibility and opt-in rates, providing insight into customer acceptance of the thermostat optimization solution
- Confirmed the thermostat optimization algorithm was operating as intended (i.e., lowering setpoints and reducing runtime for treated thermostats) over time
- Analyzed whether there are setpoint differences between weekdays/weekends and across hours of the day
- Compared data across several groups, including treated versus control

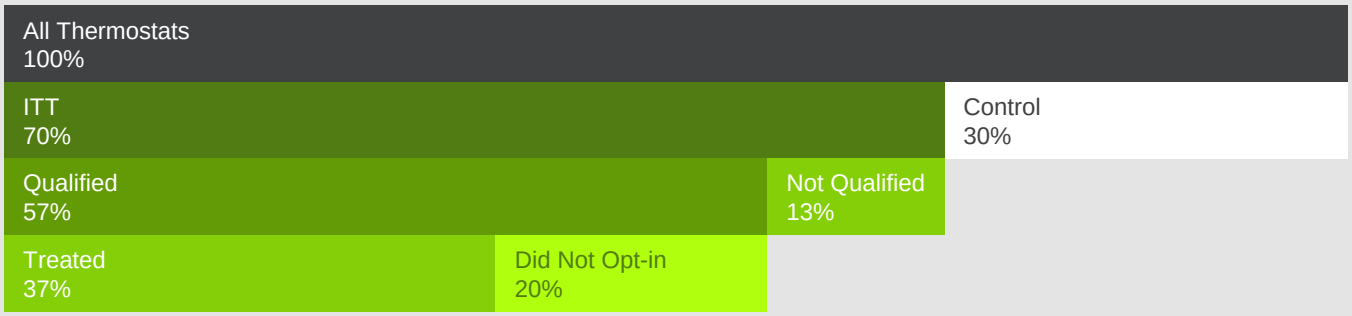
Impact Analysis

- Deployed as a randomized encouragement design (RED), with 70% of devices in the intent-to-treat (ITT) group and 30% in the control group
- Relied exclusively on thermostat telemetry data to estimate impacts after converting thermostat runtime to estimated power
- Estimated winter, winter on-peak, and winter off-peak energy savings
- Estimated energy savings for the tune-up and post-tune-up periods
- Estimated demand savings for the winter on-peak period post program deployment and demand savings for the full winter on-peak period assuming no demand savings prior to program launch

PROGRAM POPULATION & DEPLOYMENT

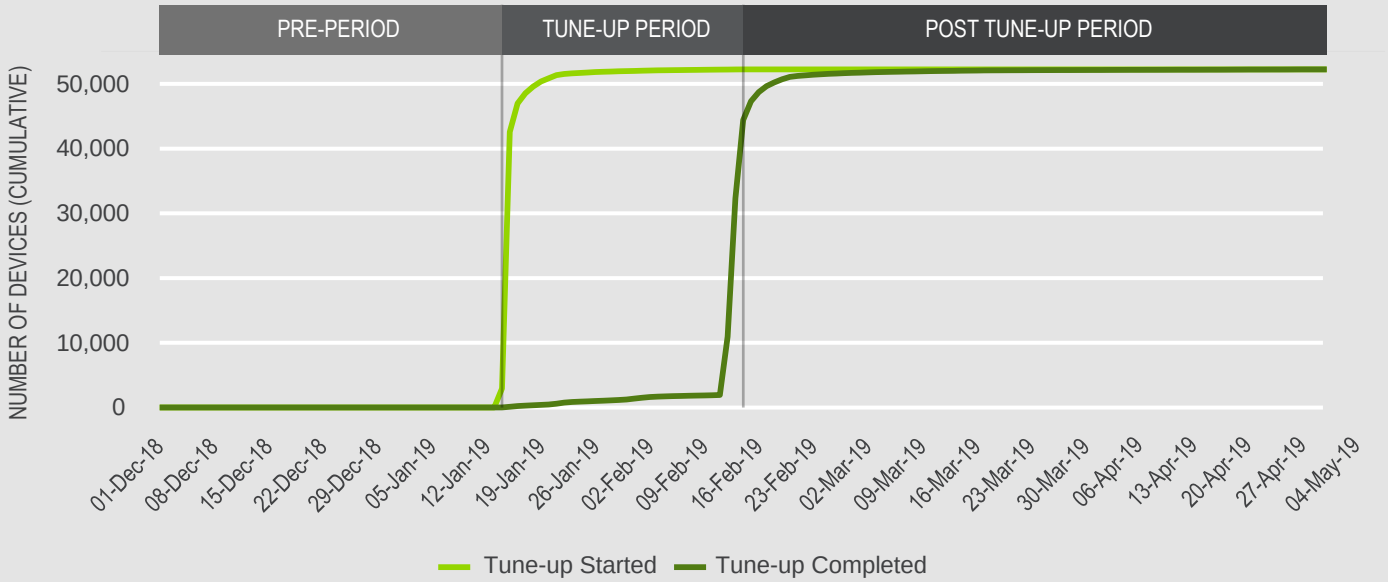
The Winter 2018-2019 SS deployment targeted 139,626 thermostats in the National Grid, Eversource, and Cape Light Compact territories. Of the total targeted population, 30 percent of devices were sorted into a control group. The remaining 70 percent were part of the ITT group and could qualify to receive the SS "offer" if they were connected to wi-fi, in heating mode, and had a heating setpoint schedule. Overall, 53 percent of the ITT devices qualified and opted-in to the program, thus receiving the SS treatment (a total of 52,238 devices).

SEASONAL SAVINGS DEVICE POPULATION



Overall, customers were quick to enroll their thermostats into the program, with 97% of enrolled thermostats beginning their treatment within the first week of the program offering. After opting-in to the program, the average time for the full SS algorithm to finish the tune-up was approximately 30 days. Navigant segmented the program period (January 14 – April 30, 2019) into the *tune-up period* and the *post tune-up period*. The delineation between the two periods occurred once 85 percent of thermostats had completed the SS tune-up. For the Winter 2018-2019 deployment, this date was February 14, 2019.

ENROLLMENT IN SEASONAL SAVINGS

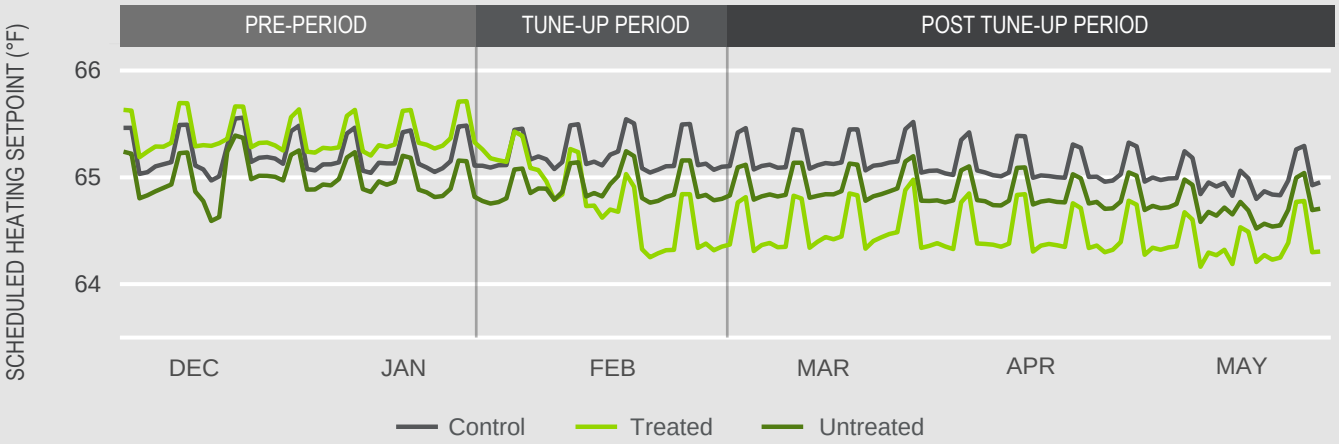


KEY FINDINGS

Exploratory Analysis

The exploratory analysis compared the average daily scheduled heating setpoints for the ITT subgroups (treated and untreated) relative to the control group's schedule. The average daily scheduled heating setpoints decreased for the treated group relative to the control group after the SS program began. The evaluation also revealed that adjustments to the heating setpoint schedules were largest overnight, with little difference between weekdays and weekends.

AVERAGE DAILY SCHEDULED SETPOINT FOR ALL THERMOSTATS



Overall, the SS adjustment resulted in an average 0.73 degree setpoint decrease and 10.9 minute per day runtime decrease for the treated group relative to the control group.

SUMMARY OF SETPOINT AND RUNTIME ANALYSIS

	Group	Pre-period	Post Tune-Up	Δ†	SS Impact‡
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.25	40.42	6.17	-
Avg. Daily Scheduled Heating Setpoints (°F)	Control	65.23	65.13	-0.11	-
	Intent-to-Treat	65.26	64.67	-0.59	-0.48
	TREATED	65.39	64.55	-0.84	**-0.73**
	UNTREATED	65.03	64.88	-0.15	-0.04
Avg. Daily Heating Runtime (min)	Control	250.12	176.36	-73.76	-
	Intent-to-Treat	251.16	172.19	-78.97	-5.21
	TREATED	259.54	174.84	-84.69	**-10.9**
	UNTREATED	240.64	168.84	-71.81	1.95

† The Δ is the difference between the post tune-up period and the pre-period.
‡ The SS impact is the difference between the Δ for the ITT or treated group and the control group.
Source: Navigant analysis of Nest thermostat telemetry data and NOAA temperature data

KEY FINDINGS

Impact Analysis

The Massachusetts PAs launched the winter SS program on January 14, 2019 to 52,238 customers across three territories. Per-thermostat energy savings were estimated at the statewide level for natural gas and non-natural gas devices. The energy savings achieved through April 30, 2019 are as follows:

STATEWIDE PER T-STAT SAVINGS

	Fuel (MMBtu)	Electric (kWh)
Natural Gas	**1.554**	**7.32**
Non-Natural Gas	**0.9447**	**17.28**

PERCENT OF HEATING LOAD SAVINGS

	Fuel	Electric
Natural Gas	**4.7%**	**4.6%**
Non-Natural Gas	**2.8%**	**6.2%**

NATURAL GAS SAVINGS SUMMARY

PA	Heating Fuel Type	Measure Life	# of Participating Thermostats	Vendor MMBtu Savings	Vendor kWh Savings	Verified MMBtu Savings‡	Verified kWh Savings‡	MMBtu Realization Rate†	kWh Realization Rate†
Statewide	Natural Gas	1	34,480	54,961	257,566	53,582	252,394	97%	98%
Eversource	Natural Gas	1	11,667	18,597	87,152	18,131	85,402	97%	98%
National Grid	Natural Gas	1	22,813	36,364	170,413	35,451	166,991	97%	98%

†Estimated savings are different between Navigant and Nest due to small differences in the per-thermostat savings.

‡Total savings are calculated using the statewide Natural Gas per-thermostat savings. For example, to calculate total kWh savings for Eversource, the statewide per thermostat savings of 7.32 kWh is multiplied by 11,667 participating Eversource Natural Gas thermostats for a total of 85,402 kWh.

NON-NATURAL GAS SAVINGS SUMMARY

PA	Heating Fuel Type	Measure Life	# of Participating Thermostats	Vendor MMBtu Savings	Vendor kWh Savings	Verified MMBtu Savings‡	Verified kWh Savings‡	MMBtu Realization Rate†	kWh Realization Rate†
Statewide	Non-Natural Gas	1	17,758	15,358	306,503	15,120	306,858	98%	100%
Cape Light Compact	Electric	1	42	-	725	-	726	-	100%
	Oil	1	591	567	10,201	558	10,212	98%	100%
	Propane	1	325	312	5,610	307	5,616	98%	100%
Eversource	Electric	1	1,302	-	22,473	-	22,499	-	100%
	Oil	1	5,912	5,673	102,041	5,585	102,159	98%	100%
	Propane	1	1,047	1,005	18,071	989	18,092	98%	100%
National Grid	Electric	1	409	-	7,059	-	7,068	-	100%
	Oil	1	6,735	6,463	116,246	6,363	116,381	98%	100%
	Propane	1	1,395	1,339	24,078	1,318	24,106	98%	100%

†Estimated savings are different between Navigant and Nest to small differences in the per-thermostat savings.

‡Total savings are calculated using the statewide Non-Natural Gas per-thermostat savings. For example, to calculate total Oil kWh savings for Cape Light Compact, the statewide per thermostat savings of 17.28 kWh is multiplied by 591 participating Cape Light Compact Oil thermostats for a total of 10,212 kWh.

RECOMMENDATIONS

Savings

- For the current 2018-2019 Winter season, the Massachusetts Program Administrators (PA) should use a realization rate of:
    - 97% for Natural Gas heating fuel savings
    - 98% for Natural Gas heating electric savings
    - 98% for Non-Natural Gas (Oil and Propane) heating fuel savings
    - 100% for Non-Natural Gas (Electric, Oil, and Propane) heating electric savings
- These realization rates can be applied to the vendor reported estimates of total savings or per-thermostat savings.

CONSIDERATIONS

Realization Rate

- For the future winter seasons where SS is deployed, the Massachusetts Program Administrators (PA) can use a realization rate of:
    - 97% for Natural Gas heating fuel savings
    - 98% for Natural Gas heating electric savings
    - 98% for Non-Natural Gas (Oil and Propane) heating fuel savings
    - 100% for Non-Natural Gas (Electric, Oil, and Propane) heating electric savings
- If these realization rates are used for future deployments, the vendor (Google) should estimate savings of therms and kWh using a two-way fixed effects model and a Natural Gas/Non-Natural Gas segmentation.
- For Winter 2019-2020, evaluate the SS program to better inform a realization rate for inclusion in the Technical Reference Manual.

Future Research

- The PAs should seek to improve the runtime to energy estimates by developing an estimate of natural gas space heating consumption per thermostat for homes with furnaces or with boilers. This would be combined with the total thermostat runtime to update the runtime to energy estimates.

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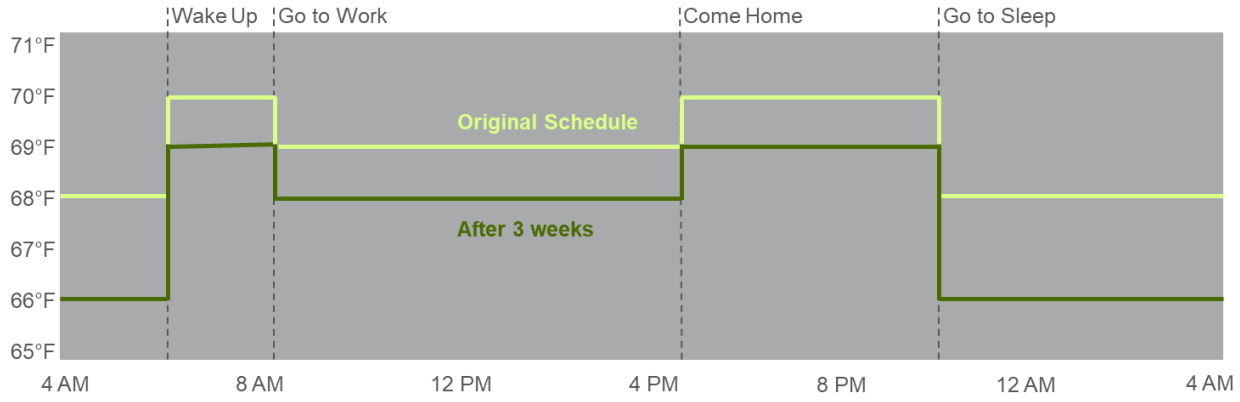
1. INTRODUCTION

The Massachusetts (MA) Program Administrators (PAs) National Grid, Eversource Energy, and Cape Light Compact partnered with Google in the 2018-2019 winter season to offer the MA PA's customers with an existing Google Nest thermostat an energy savings opportunity, the Seasonal Savings (SS) program. SS is a temperature optimization program designed to make small incremental adjustments to scheduled setpoints over a 3-4-week period (i.e., tune-up period) while maintaining customer comfort (Figure 1-1). On average, scheduled setpoints are adjusted downward by 0.5°F-1.5°F during the heating season, with the largest temperature adjustments taking place when customers are typically asleep or away from home (e.g., nighttime and morning through early afternoon on weekdays).[1]

Figure 1-1. Illustrative Setpoint Schedule Adjustments



Source: Navigant, Google[1]

Navigant completed an evaluation of the 2018-2019 SS winter program with a focus on savings by fuel type and customer acceptance of the solution, which are essential in determining whether SS is a cost-effective offering and whether to continue deployment.[2] This report presents these findings in several sections:

- Section 2 summarizes the evaluation methodology
- Section 3 outlines the data sources and data management used in this evaluation
- Section 4 presents results from the exploratory and impact analyses
- Section 5 presents findings and recommendations

1.1 Evaluation Objectives

The objectives of the 2018-2019 winter temperature optimization evaluation were to answer the questions outlined in Table 1-1.

[1] "Learn about Seasonal Savings," Google, https://nest.com/support/article/What-is-Seasonal-Savings.

[2] This evaluation did not examine whether temperature optimization is cost-effective for the heating system, program administrators, or customers.

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Table 1-1. Temperature Optimization Research Questions

Research Questions	Evaluation Approach
• What percent of thermostats/customers enrolled in the program by the relevant PA and fuel combinations? • What percent of customers participate in both summer and winter SS? • What percent of the Massachusetts Department of Energy Resources winter SS participants re-enrolled? • Are there any effects of summer SS or previous winter SS on 2018/2019 setpoints or runtime? • Did the program have the intended effect on scheduled setpoints and were effects similar across the relevant PA and fuel type categories? • What was the impact of SS on heating runtime, by relevant PA and fuel combinations, by day and over the winter season?	Exploratory analysis
• How much oil, gas, electric, and propane energy was saved during the tune-up and post tune-up periods? • Where adequate data is available, how much energy was saved for certain PAs by fuel type (e.g., National Grid-Gas and Eversource-Gas)? • How much electric energy was saved during on-peak and off-peak hours? • How much winter peak electric demand was reduced? • How much energy would have been saved if SS ran during the whole winter?	Impact analysis

Source: Navigant

1.2 Nest Population

There were 139,626 Nest thermostats in the SS program offering. Table 1-2 shows the number of thermostats by PA.

Table 1-2. Thermostat Counts by PA

Program Administrator	Total Devices
National Grid - Electric	22,343
National Grid - Gas	61,691
Eversource - Electric	21,476
Eversource - Gas	29,571
Cape Light Compact	4,545
All	**139,626**

Source: Navigant analysis of Nest thermostat device data

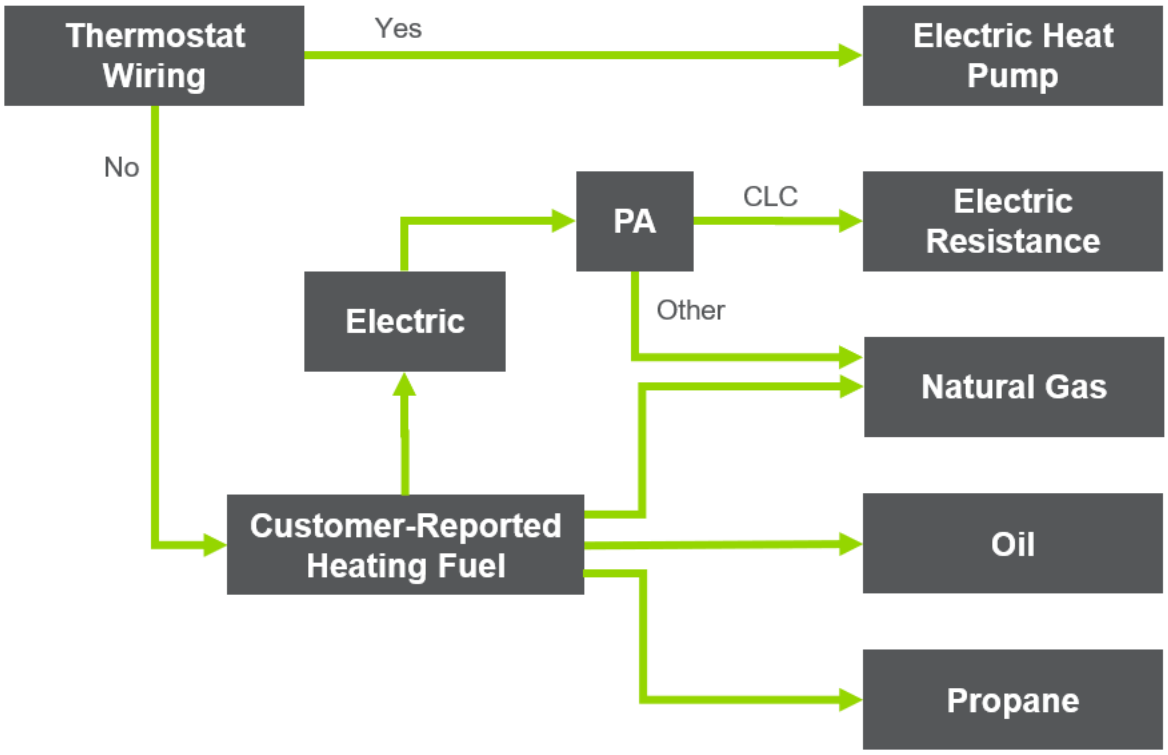
Google assigned the Nest population to fuel types based on thermostat wiring and customer reports.[3] Thermostats with heat pump wiring were mapped to electric heat pumps. Those without heat pump wiring were assigned primarily to the self-reported heating fuel. Customers that self-reported electric heat but

[3] In addition, Google provides an indication of whether the heating equipment is boiler or furnace, and whether it has one or multiple stages.

did not have heat pump wiring were assigned to the natural gas fuel type, except for Cape Light Compact customers[4]. For Cape Light Compact customers that self-reported a gas fuel type, thermostats were mapped to propane as there is no natural gas service in that area. Google mapped each thermostat to a PA based on customer ZIP codes and the corresponding PA service areas.

Figure 1-2 shows the logic behind the heating fuel type assignment used by Google.

Figure 1-2. Assignment of Heating Fuel Type



Source: Navigant

This report presents results for three groups:

- All thermostats, irrespective of fuel type or PA (abbreviated as “All”)
- All thermostats with natural gas as the heating fuel type (abbreviated as “Gas-All”)
- All thermostats with non-gas heating fuel types (abbreviated as “Non-Gas-All”)

Appendix A through Appendix D present results for other segments by fuel type and PA. Table 1-3 shows the distribution of thermostats across the four fuel types and PAs.

[4] Cape Light Compact electric customers in the National Grid gas service area were designated as National Grid gas customers.

Table 1-3. Thermostat Counts by Heating Fuel and PA

Fuel Type	National Grid	Eversource	Cape Light Compact	Total
Gas-All	**61,691**	**29,571**	**-**	**91,262**
Non-Gas-All	**22,343**	**21,476**	**4,545**	**48,364**
Oil	17,076	14,360	2,501	33,937
Propane	3,967	2,877	1,776	8,629
Electric	1,300	4,239	268	5,798
All	**84,034**	**51,047**	**4,545**	**139,626**

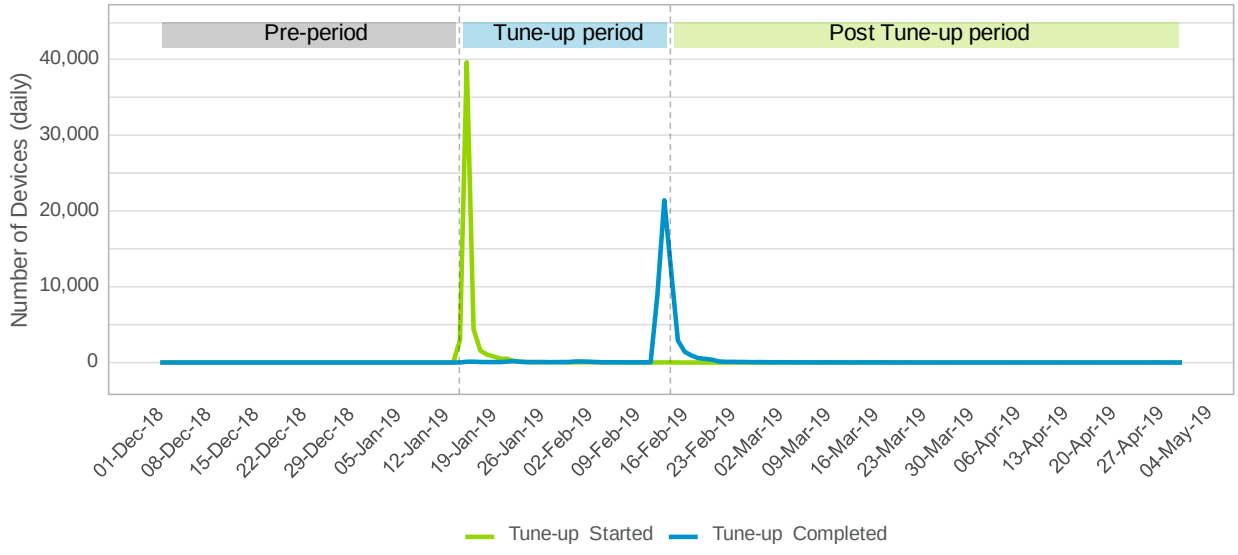
Source: Navigant analysis of Nest thermostat device data

1.3 Program Enrollment

The SS program is implemented as a randomized encouragement design (RED). Of the 139,626 thermostats targeted for the program, Google assigned 70% (97,746) to the intent-to-treat (ITT) group and 30% (41,880) to the control group. Only thermostats in the ITT group could qualify and enroll in the program.

In total, 52,238 thermostats enrolled in the SS program. Figure 1-3 shows the number of thermostats starting and ending the SS tune-up over the winter. The green line represents the number of thermostats enrolled at each date, with the first thermostats opting in on January 14, 2019 (the tune-up start date) and the final thermostats opting in on February 19, 2019. Customers were quick to enroll their thermostats into the program, 97% of enrolled thermostats (50,865) began their treatment within the first week of the program offering. The blue line shows the number of thermostats that completed the SS algorithm tune-up on each date.

Figure 1-3. Daily Enrollment in Seasonal Savings

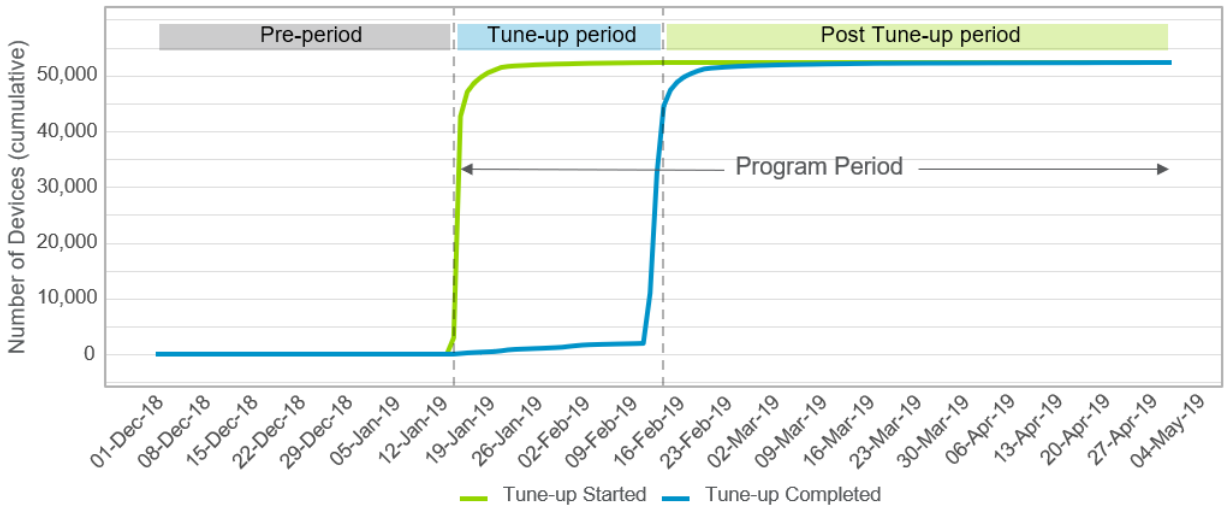


Source: Navigant analysis of Nest thermostat enrollment data

Navigant segmented the program period (January 14–April 30, 2019) into the tune-up period and the post tune-up period. The delineation between the two periods occurred once 85% of thermostats had completed the SS tune-up. For the winter 2018-2019 deployment, this was February 14, 2019.

Figure 1-4 presents the enrollment information as a cumulative total of thermostats both starting and completing tune-up each day over the study period. The average time for the full SS algorithm to finish tune-up was approximately 30 days.

Figure 1-4. Cumulative Enrollment in Seasonal Savings

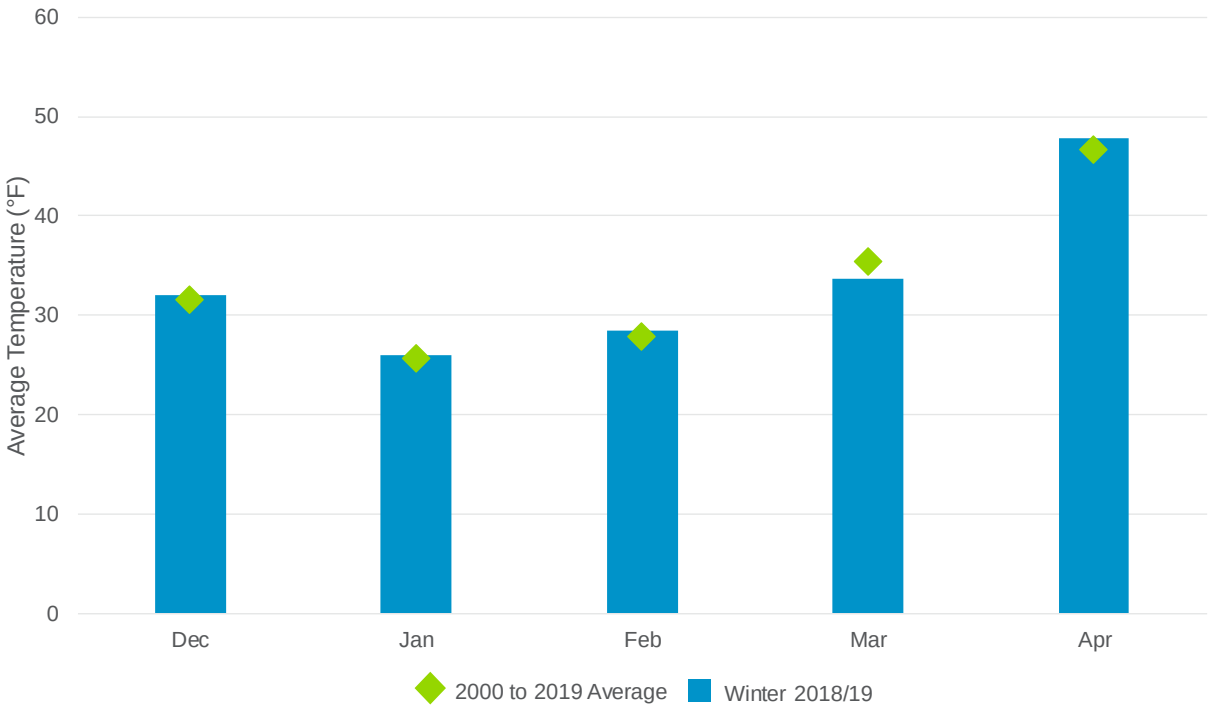


Source: Navigant analysis of Nest thermostat enrollment data

1.3.1 Winter Weather 2018-2019

The average temperature was in line with the 20-year average across Massachusetts during the pre-program and program period. A monthly comparison of the 2018-2019 average to the 20-year average can be found in Figure 1-5. December through February, average temperatures deviated little from the historic average, while March experienced cooler weather and April experienced warmer weather.

Figure 1-5. Average Winter (December to April) Temperatures, All Massachusetts



Source: Navigant analysis of the monthly/seasonal climate summary tables for Massachusetts available from the Northeast Regional Climate Center

2. EVALUATION METHODS

This section describes the evaluation framework and methods used for the 2018-2019 winter SS program deployment.

2.1 Experimental Design

Google deployed the SS program using a RED, in which all customers in a PA's service area with a Nest thermostat were randomly assigned to one of two groups. These two groups are the ITT group (where participants are randomly assigned to receive the program offering) and the control group (where participants are randomly assigned to not receive the program offering).[5] Prior to conducting the evaluation, Navigant verified the balance of the ITT and control groups across key variables (e.g., scheduled setpoints and runtime).[6]

Some thermostats in the ITT group do not qualify to participate in the program. Qualification requirements include the following:

1. A Nest thermostat is installed and the customer has an online account
2. A heating system is connected to the thermostat
3. A setpoint schedule is programmed

All qualified customers were provided the program offering on both the thermostat and through Nest's mobile app. Most qualified ITT customers chose to opt in and enroll into the program (65%), while others did not (35%). The treated group represents the customers that opted in. Thermostats that were part of the ITT group but either did not qualify or did not opt in are referred to as the untreated group. SS savings are evaluated by comparing the ITT group (both treated and untreated thermostats) to the control group. The savings estimate is then scaled by the opt-in rate to calculated savings from treated thermostat.

[5] For each PA, 70% of thermostats were randomly assigned to the ITT group while the remaining 30% were assigned to the control group.

[6] Prior to the deployment of the program, Google randomized the targeted thermostat population 20 times and Navigant selected the randomization for each evaluation segment with the best balance. However, Google mistakenly deployed the incorrect randomizations. The results of the post-deployment balance checks are in Appendix D.

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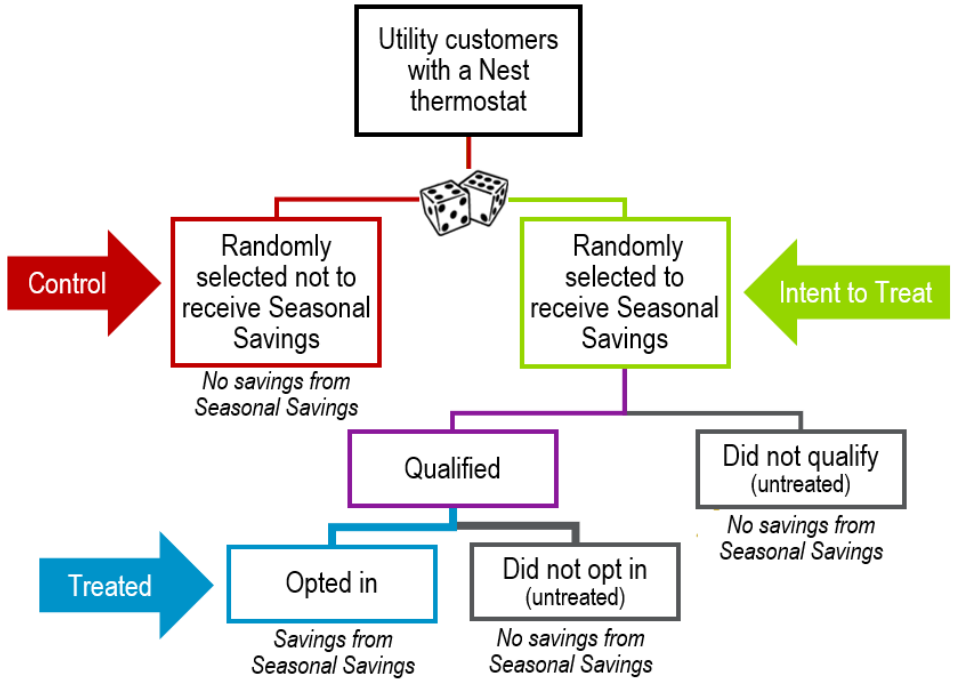
Figure 2-1 illustrates the RED design for the SS program.

Figure 2-1. RED Illustration



Source: Navigant

Table 2-1 tallies the thermostats assigned to the control and ITT groups, and the number of thermostats that did not qualify or did/did not opt in. The randomization assigned 70% of thermostats to the ITT group. Within the ITT, approximately 18% of the assigned thermostats did not qualify and another 28% chose not to opt in to the SS program. The remaining 53% of ITT thermostats were enrolled in the program.

Table 2-1. Implementation of the 2018-2019 Winter Seasonal Savings Program

	Nests	Percent of All	Percent of ITT	Percent of Qualified
All Thermostats	139,626	100%	-	-
Control	41,880	30%	-	-
ITT	97,746	70%	100%	-
Not Qualified	17,936	13%	18%	-
Qualified	79,810	57%	82%	100%
Did Not Opt in	27,572	20%	28%	35%
Treated	52,238	37%	53%	65%

Source: Navigant analysis of Nest thermostat enrollment data

The evaluation timeframe was December 1, 2018 through April 30, 2019. The evaluation was broken up into a pre-period (December 1-January 13) and a post period (January 14-April 30), as SS deployment began on January 14, 2019. The post period was further broken up into the tune-up period (January 14-February 13) and the post tune-up period (February 14-April 30) based on an analysis of the thermostat population's scheduled heating setpoint data. The tune-up period lasted roughly 4 weeks, during which

thermostats began their incremental schedule adjustments. The full effect of SS was not felt until the thermostats finished their tune-up, after which the post tune-up period began.

2.2 Exploratory Analysis

The evaluation team analyzed thermostat-level participation data and thermostat telemetry data to:[7]

- Analyze setpoint schedules and thermostat heating runtime during the pre-period, tune-up period, and post tune-up period to assess whether the impact of temperature optimization was evident in the data.
- Compare data across several groups, including ITT versus control and treated versus untreated versus control.
- Conduct a time differentiated analysis by comparing differences between weekdays/weekends, and the hour-of-the-day.
- Compare actual setpoints to scheduled setpoints.[8]

For the exploratory analysis, the control group is often the basis of comparison and serves as the counterfactual for the combined treated and untreated groups (the ITT group), i.e., what would have happened had the thermostats in the ITT not been deployed as part of the SS program. Comparing the treated and untreated groups may lead to false conclusions as the characteristics that influence whether a thermostat ends up in the treated group (e.g., connectivity, mode) may also influence the setpoints and runtime of the thermostat. The differences between the treated and untreated groups may be a result of preexisting characteristics, not necessarily from enrollment in the SS program.

2.3 Impact Analysis

Navigant conducted the impact analysis to estimate the energy savings and peak demand savings from temperature optimization for the treated group.[9] The impact analysis consisted of a runtime to energy conversion, econometric modeling to calculate savings, and a realization rate comparison to Google's calculated savings.

2.3.1 Runtime to Energy

The data provided by the Nest thermostats included the runtime of each controlled piece of equipment, but not the energy consumed by each piece of equipment. This subsection describes the process Navigant used to convert the runtime provided by the Nest thermostats into a measure of energy consumption for each piece of equipment.

For this analysis, Navigant did not adjust capacity or efficiency assumptions based on operating conditions. Navigant expects that this assumption is most impactful for heat pumps, which only constitute 4% of program participants.

[7] The body of the report only contains the natural gas-all and non-natural gas-all segments. Results by sub-segments (PA and other fuel types) are found in the Appendix.

[8] The actual setpoints are the setpoints that dictate the temperature the home is heated to. Actual setpoints can differ from the setpoint schedule when customers make manual adjustments to their thermostat or if customers have occupancy detection activated.

[9] The savings estimate for the ITT group represents an unbiased estimate of the effect of encouragement on energy use while the savings estimate for the treated group represents an unbiased estimate of the effect of the program intervention on energy use.

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Space heating equipment is usually rated based on its capacity and efficiency. The capacity can generally be provided in two forms: input capacity or output capacity. The input capacity is more commonly used for fuel-powered equipment such as furnaces; it specifies the amount of energy consumed by the piece of equipment per unit time. The output capacity is more often used in heat pumps and specifies the amount of heat provided by the unit per unit time. This means that the input capacity is linked to the amount of energy that a utility must provide to the equipment, while the output capacity is linked to the amount of energy that must be provided to the conditioned space to meet the heating load. These two variables are connected to each other via the operating efficiency of the equipment, as shown in Equation 2-1.

Equation 2-1. Output Capacity

$$Output\ Capacity = Input\ capacity \times Efficiency$$

Navigant estimated the average input capacity for each type of fuel-fired space heating equipment. Navigant estimated the average output capacity and operating efficiency of heat pump equipment across MA, which allowed for conversions between output and input capacity for heat pump equipment. This, in turn, allowed Navigant to estimate the energy provided by each piece of equipment, as described later in this subsection. Navigant leveraged various data sources to obtain accurate estimates of average capacity and operating efficiency, including previous potential studies, the RES 1 Baseline Load Shape Study, past DOE regulatory analyses and the Massachusetts Technical Reference Manual.[10]

To calculate the hourly energy consumption by each piece of equipment, Navigant multiplied the input capacity (energy per hour) by the percent of the hour the Nest thermostat recorded runtime, as shown in Equation 2-2.

Equation 2-2. Input Capacity to Energy Consumption

$$Energy\ Consumption = Input\ Capacity \times Percent\ Runtime$$

For equipment that is usually rated by output capacity, such as heat pumps, Navigant applied the conversion between output and input capacity, leading to Equation 2-3.

Equation 2-3. Output Capacity to Energy Consumption.

$$Energy\ Consumption = \frac{Output\ Capacity}{Efficiency} \times Percent\ Runtime$$

Unlike houses heated by furnaces or heat pumps, houses heated by boilers are typically divided into different zones with each zone having its own hydronic heat loop and thermostat. And, unlike furnaces and heat pumps, many boiler models retain a significant amount of heat within the boiler when the gas valve is not firing. To account for these differences in boiler-heated homes, Navigant used data from a previous boiler metering study to develop a ratio of the amount of time that a boiler controlling thermostat is calling for heat to the amount of time that the boiler is consuming energy to produce heat.

After Navigant estimated the primary heating fuel use, Navigant estimated the associated electric usage for furnace fans and boiler pumps (auxiliary electric consumption). These conversions enabled Navigant to fully quantify the energy impacts from this program.

The resulting conversion factors for both fuel and electric consumption are found in Table 2-2.

[10] Note to MA PAs: We will provide the specific references in a table within this section.

Table 2-2. Runtime to Energy Conversion Factors

	Call time to Runtime Ratio for Fuel Consumption	Fuel Consumption (*Therms per Hour of Heating Call Time*)	Auxiliary Electric Consumption / Electric Consumption (*kWh per Hour of Heating Call Time*)
Natural Gas – High Stage Furnace	1:1	0.79	0.48
Natural Gas – Low Stage Furnace	1:1	0.50	0.26
Natural Gas – Boiler	1:0.7	0.91	0.30
Oil – Furnace	1:1	0.92	0.48
Oil – Boiler	1:0.7	0.86	0.30
Propane - Furnace	1:1	0.74	0.48
Electric – Central HP (no elec. res.)	1:1	N/A	3.30
Electric – Space Heater	1:1	N/A	7.80

Source: Navigant analysis

2.3.2 Econometric Modeling

Navigant used linear fixed effects (or difference-in-differences) regression models to estimate energy and power savings. These savings are associated with the thermostats that were randomly assigned to receive the program offering; the respective savings estimates are the average effect of being randomly assigned to receive the SS algorithm. This value is then scaled by the program opt-in rate to estimate the savings per treated thermostat. Table 2-3 details the calculations of the various savings estimates.

Equation 2-4 specifies the model used to estimate energy savings. The converted and formatted Nest telemetry runtime data was aggregated up to the daily level for each thermostat for all models using this specification.

Equation 2-4. Linear Fixed Effects Model – Energy Savings

$$\boldsymbol{EDU_{it} = \alpha_i + \gamma_t + \beta(Post_t \cdot ITT_i) + \varepsilon_{it}}$$

Where,

EDU_{it}	is the estimated daily usage in therms or kWh by thermostat *i* on date *t.*
α_i	is a thermostat-specific fixed effect for thermostat *i*; this picks up all thermostat-specific characteristics that do not change through time, like household square footage.
γ_t	is a time-specific fixed effect for the date *t;* this picks up temporal differences between days, like weather and daylight hours.
$Post_t \cdot ITT_i$	is a binary variable taking a value of 1 when thermostat *i* is in the ITT group and date *t* is on or after the start of the SS program (January 14, 2019).
β	is the average daily per-thermostat therms or kWh impact of participating in the ITT group after January 14, 2019.
ε_{it}	is the cluster-robust error term for thermostat *i* during date *t*; these cluster-robust errors account for heteroskedasticity and autocorrelation at the thermostat level.

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To predict savings for the program as if it had deployed December 1, 2018 (the Effective Winter period), Navigant modified Equation 2-4 to include an HDD interaction. Equation 2-5 describes the model used to estimate Effective Winter savings.

Equation 2-5. Linear Fixed Effects Model – Effective Winter Energy Savings

$$\boldsymbol{EDU_{it} = \alpha_i + \gamma_t + \beta_1(Post_t \cdot ITT_i) + \beta_2(Post_t \cdot ITT_i \cdot HDD_{it}) + \beta_3 HDD_{it} + \varepsilon_{it}}$$

Where,

EDU_{it}	is the estimated daily usage in therms or kWh by thermostat *i* on date *t.*
α_i	is a thermostat-specific fixed effect for thermostat *i*; this picks up all thermostat-specific characteristics that do not change through time, like household square footage.
γ_t	is a time-specific fixed effect for the date *t;* this picks up temporal differences between days, like weather and daylight hours.
$Post_t \cdot ITT_i$	is a binary variable taking a value of 1 when thermostat *i* is in the ITT group and date *t* is on or after the start of the SS program (January 14, 2019).
β_1	is the average daily per-thermostat therms or kWh impact of participating in the ITT group after January 14, 2019.
β_2	is the average daily per-thermostat therms or kWh impact per HDD of participating in the ITT group after January 14, 2019.
β_3	is the average daily per-thermostat therms or kWh impact per HDD.
HDD_{it}	is the total HDD (base 60) experienced by thermostat *i* during date *t*; this value is determined through temperature records from an assigned Quality Controlled Local Climatological Data weather station based on a thermostat's ZIP code.
ε_{it}	is the cluster-robust error term for thermostat *i* during date *t*; these cluster-robust errors account for heteroskedasticity and autocorrelation at the thermostat level.

Navigant used a modified version of Equation 2-4 that used aggregated hourly rather than daily observations to estimate demand savings. This model used similar linear fixed effects but heating degree hours (HDH) was added as a regressor. Equation 2-6 describes the model used to estimate power savings.

Equation 2-6. Linear Fixed Effects Model – Demand Savings

$$\boldsymbol{AHP_{ith} = \alpha_i + \gamma_t + HDH_{ith} + \beta(Post_t \cdot ITT_i)} + \varepsilon_{ith}$$

Where,

AHP_{ith}	is estimated average power in kW used by thermostat *i* during date *t* and hour *h.*
α_i	is a thermostat-specific fixed effect for thermostat *i*; this picks up all thermostat-specific characteristics that do not change through time, like household square footage.
γ_t	is a time-specific fixed effect for the date *t;* this picks up temporal differences between days, like weather and daylight hours.
HDH_{ith}	is the total HDH (base 60) experienced by thermostat *i* during date *t* and hour *h*; this value is determined through temperature records from an assigned Quality Controlled Local Climatological Data weather station based on a thermostat's ZIP code.

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$Post_t \cdot ITT_i$	is a binary variable taking a value of 1 when thermostat *i* is in the ITT group and date *t* is on or after the start of the SS program (July 2, 2018).
β	is the average hourly per-thermostat kW impact of participating in the ITT group from January 14, 2019 through January 31, 2019 between 5 p.m. and 7 p.m.
ε_{ith}	is the cluster-robust error term for thermostat *i* during date *t* and hour *h*; these cluster-robust errors account for heteroskedasticity and autocorrelation at the thermostat level.

Navigant estimated energy and demand impacts for each evaluation segment. The team multiplied average daily energy savings by the appropriate number of program days (after the first program start date) and the number of thermostats in the ITT group to calculate total program energy savings that result from treatment. To calculate total demand savings, Navigant multiplied average hourly demand savings by the number of thermostats in the ITT group. Table 2-3 identifies the various savings statistics.

Table 2-3. Savings Calculations

Savings Type	Statistic	Calculation
Energy	Average daily savings per treated thermostat	$\hat{\gamma} = \frac{-\hat{\beta}}{SS\ Opt\ In\ Rate}$
	Total savings	$-\hat{\beta} \times Total\ Number\ of\ ITT\ Days\ Post\ Program\ Start$
	Average total savings per treated thermostat	$\frac{Total\ Savings}{Total\ Number\ of\ Treated\ Thermostats}$
	Average savings (Percent of heating load)	$\frac{\hat{\gamma}}{(Avg\ Daily\ Treated\ Energy\ Usage\ Post\ Program\ Start + \hat{\gamma})}$
Energy – Effective Winter	Total Savings	$(-\widehat{\beta_1} \times Total\ Number\ of\ ITT\ Days\ Dec\ 1\ to\ Apr\ 30 + -\widehat{\beta_2} \times Total\ Number\ of\ ITT\ HDD\ Dec\ 1\ to\ Apr\ 30) \times Total\ Number\ of\ ITT\ Thermostats$
Demand	Average daily demand per treated thermostat	$\hat{\gamma} = \frac{-\hat{\beta}}{SS\ Opt\ In\ Rate}$
	Total demand savings	$-\hat{\beta} \times Total\ Number\ of\ ITT\ Thermostats$
	Average demand savings (Percent of heating load)	$\frac{\hat{\gamma}}{(Avg\ Hourly\ Treated\ Demand\ Post\ Program\ Start + \hat{\gamma})}$

Source: Navigant

The impact evaluation key outputs (Table 2-4) detail the energy and demand savings achieved through April 30, 2019. All outputs are generated for each evaluation segment, meaning each evaluation segment was individually modeled. Summarized impacts at the PA and heating fuel type level in Section 4.2 are estimated using the Natural Gas and Non-Natural Gas evaluation segment savings.

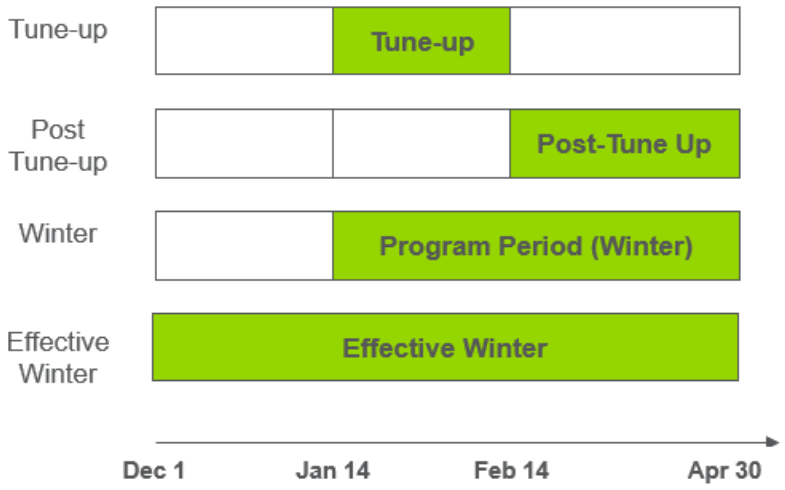
Table 2-4. Periods Analyzed in the SS Program

Measure	Period	Definition
Energy	Tune-Up	All hours January 14 through February 13 (85% of devices completed tune-up by this date)
	Post Tune-Up	All hours February 14 through April 30
	Winter	All hours December 1 through April 30, while the SS program is active
	Effective Winter	All hours December 1 through April 30, assuming the SS program were active the entire period
	Winter On-Peak (Electric-only)	Weekdays, non-holidays from 7 a.m. to 11 p.m. October through May, while the SS program is active
	Winter Off-Peak (Electric-only)	All other hours from October through May, including weekends and holidays, while the SS program is active
Demand	Winter Demand (Electric-only)	Weekdays, non-holidays from 5 p.m. to 7 p.m., December 1 through January 31, while the SS program is active
	Adjusted Winter Demand (Electric-only)	Weekdays, non-holidays from 5 p.m. to 7 p.m., December 1 through January 31 (zero demand savings prior to program launch)

Source: Navigant

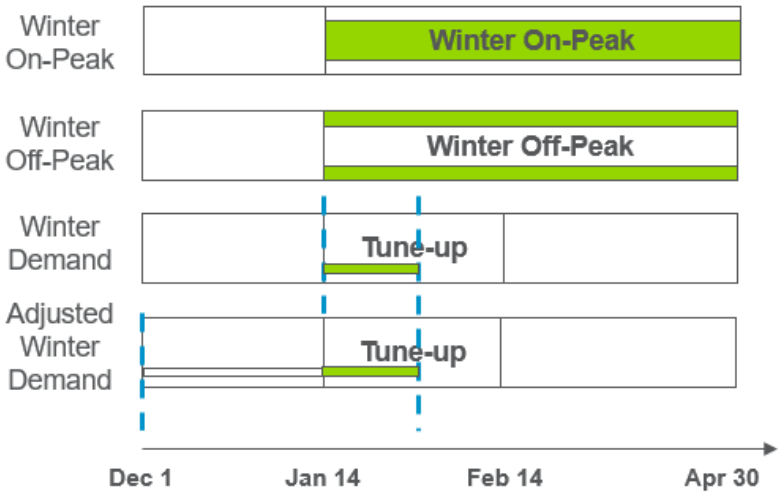
Figure 2-2 and Figure 2-3 illustrate the periods detailed in Table 2-4..

Figure 2-2. Winter Energy Periods



Source: Navigant

Figure 2-3. Winter Electric-Only Periods



Note: The figure is illustrative. Weekend and holidays are not shown.
Source: Navigant

2.3.3 Realization Rate

Google estimated energy and demand savings in parallel with Navigant's estimation of energy and demand impacts. For its evaluation, Google used two model specifications: a one-way fixed effect model that included weather data (HDD) and a two-way fixed effects model identical to Navigant's. Google ran both models for the natural gas and non-natural gas heating segments, as well as for the whole thermostat population. All models were estimated on converted runtime, using Navigant's runtime to energy conversions in Table 2-2.

Navigant developed a realization rate for the natural gas and non-natural gas segments, calculated as the ratio of Navigant's savings estimate to the savings reported by Google using the two-way fixed effects model. These values are shown in Section 4, Analysis and Results.

SS is an example of a temperature optimization offering. Other vendors have different algorithms which may result in somewhat different performance within one year and in subsequent years. The realization rate developed by Navigant for the Google implemented program would not be applicable to any new vendors.

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3. DATA SOURCES

Navigant used data from two sources for the program evaluation:

- Thermostat information and 15-minute telemetry data for December 2018 through April 2019, provided by Google, with an accompanying device file containing thermostat-specific information
- Hourly weather data across Massachusetts for 2018-2019, retrieved from the National Oceanic and Atmospheric Administration (NOAA).

3.1 Google Nest Thermostat Data

Navigant relied on thermostat telemetry data from all Nest thermostats in the 2018-2019 deployment for the exploratory and impact analyses. The team took several steps to filter and clean the data to prepare it for the regression analysis with input from the PAs.

- **No telemetry data:** Navigant received a file detailing thermostat-specific information alongside the telemetry data. If a thermostat in this file did not appear within the telemetry file, it was marked invalid and made ineligible for savings. This is the only cleaning step that categorizes thermostats as ineligible for savings.
- **No usable runtime:** Any thermostat that had telemetry data but did not have any available heating runtime information (i.e., all records were shown to be of value N/A for heating runtime) was removed from the final modeling data; however, these thermostats were still eligible for savings.
- **No complete days:** Because the impact analysis requires data aggregated to the daily level, Navigant could not include aggregated daily observations that did not have numeric runtime information during all 96 of its constituent 15-minute intervals. Some thermostats were completely removed from the modeling data due to this step; however, they were still eligible for savings.
- **No pre-/post period data:** If a thermostat did not have any records in either the pre- or post (tune-up plus post tune-up) periods, it was removed from the analysis; however, they were still eligible for savings.

Table 3-1 shows the number of thermostats that were removed from the analysis data. Only the remaining thermostats and their data were used in the exploratory and impact analyses.

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Table 3-1. Data Management

	ITT		Control		Total	
	Count	Percent	Count	Percent	Count	Percent
Thermostats in Device File	**97,746**	**100.00%**	**41,880**	**100.00%**	**139,626**	**100.00%**
No telemetry data	2,189	2.24%	1,050	2.51%	3,239	2.32%
Participating Thermostats	**95,557**	**97.76%**	**40,830**	**97.49%**	**136,387**	**97.68%**
No usable runtime	16	0.02%	3	0.01%	19	0.01%
No complete days	112	0.11%	43	0.10%	155	0.11%
No pre-/post period data	1,609	1.65%	621	1.48%	2,230	1.60%
Total Removed Thermostats	**3,926**	**4.02%**	**1,717**	**4.10%**	**5,643**	**4.04%**
Remaining Thermostats	**93,820**	**95.98%**	**40,163**	**95.90%**	**133,983**	**95.96%**

Source: Navigant analysis of Nest thermostat device and telemetry data

Navigant applied savings estimates to treated devices that had both telemetry and device data. Table 3-2. shows the number of devices eligible for savings. Only seven thermostats in the Gas-All segment were missing telemetry data and therefore did not accrue savings.

Table 3-2. Devices Eligible for Savings

	Gas-All		Non-Gas-All		Total	
	Count	Percent	Count	Percent	Count	Percent
Treated Thermostats in Device File	**34,480**	**100.00%**	**17,758**	**100.00%**	**52,238**	**100.00%**
No telemetry data	7	0.02%	0	0.00%	7	0.00%
Treated Thermostats Eligible for Savings	**24,473**	**99.98%**	**17,758**	**100.00%**	**52,231**	**100.00%**

Source: Navigant analysis of Nest thermostat device and telemetry data

3.2 NOAA Temperature Data

To provide context to the exploratory and impact analysis results (as well as to produce an effective winter savings estimate), Navigant used 2018-2019 temperature data from NOAA for 22 Quality Controlled Local Climatological Data weather stations across Massachusetts. Navigant pulled and cleaned the data, then calculated HDH (base 60°F) for all intervals. To link the weather data to individual thermostats, Google assigned each thermostat to a single weather station based on its geographic location using a ZIP code to weather station map created by Navigant.

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4. ANALYSIS AND RESULTS

This section of the report presents results from the exploratory analysis and impact analysis, including realization rates.

4.1 Exploratory Analysis

The exploratory analysis presents findings from an analysis of setpoint schedules and thermostat heating runtime. Key findings include:

- The heating setpoint schedules for the treated thermostats were adjusted downward during the program period by an average of 0.73°F resulting in a heating runtime reduction of 10.9 minutes.
- The largest setpoint adjustments took place during the middle of the night, when customers were likely to be asleep—1.50°F. This is different than the 2018 summer SS program which saw the largest adjustments during the middle of the weekdays.

4.1.1 Setpoint and Runtime Summary

Table 4-1 provides the average daily scheduled heating setpoints and daily heating runtime for the control, ITT, and treated and untreated subgroups. The exploratory analysis compares the scheduled heating setpoints and heating runtimes between the pre-period and post tune-up period for each group. The analysis found that the SS program made the intended adjustments to scheduled heating setpoints. The SS adjustment resulted in a downward shift to scheduled setpoints for the treated group relative to the control group by 0.73°F, on average, after the tune-up completed. The treated group also exhibited an average reduction of 11 minutes in daily runtime relative to the control group.

Table 4-1. Summary of Exploratory Setpoint and Runtime Analysis

	Group	Pre-Period	Post Tune-Up	Δ†	SS Impact‡
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.25	40.42	6.17	-
Average Daily Scheduled Heating Setpoints (°F)	Control	65.23	65.13	-0.11	-
	Intent-to-Treat	65.26	64.67	-0.59	-0.48
	Treated	65.39	64.55	-0.84	**-0.73**
	Untreated	65.03	64.88	-0.15	-0.04
Average Daily Heating Runtimes (min)	Control	250.12	176.36	-73.76	-
	Intent-to-Treat	251.16	172.19	-78.97	-5.21
	Treated	259.54	174.84	-84.69	**-10.9**
	Untreated	240.64	168.84	-71.81	1.95

† The Δ is the difference between the post tune-up period and the pre-period.
‡ The SS impact is the difference between the Δ for the ITT or treated group and the control group.
Source: Navigant analysis of Nest thermostat telemetry data and NOAA temperature data

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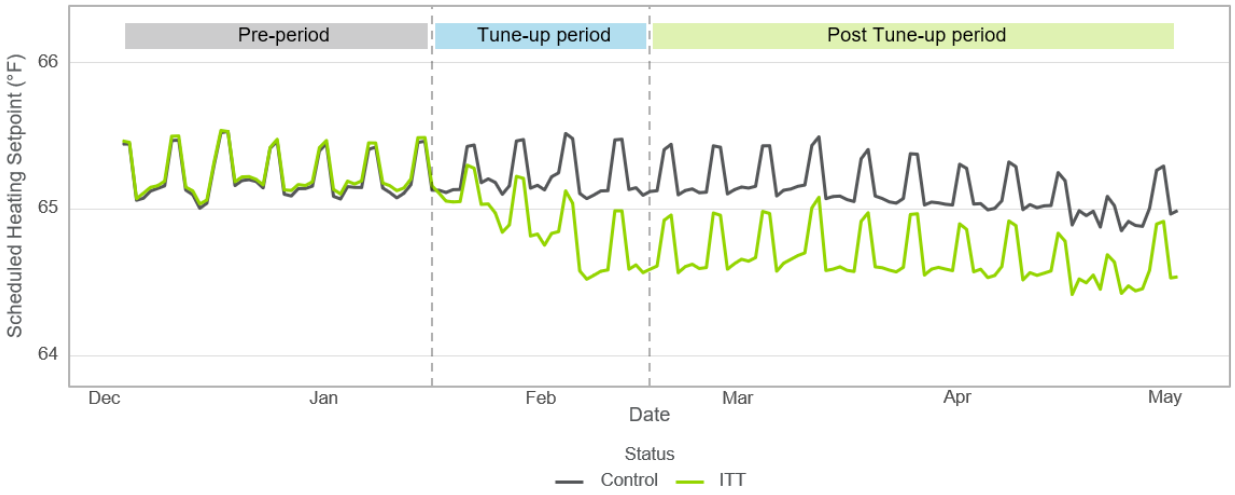
Figure 4-1 and Figure 4-3 present the relative average daily scheduled heating setpoints for the RED groups (ITT and control) and for the treatment subgroups (treated, untreated, and control). Figure 4-2 and Figure 4-4 present this information after the control group has been differenced out from the other groups. The control group is the basis for comparison and is thus represented by the x-axis in these figures.

Figure 4-1 shows average scheduled heating setpoints across all days for both the ITT and control groups. During the pre-period, the ITT and control groups have similar setpoint schedules; this is by design and a result of the RED where thermostats are randomly assigned to either the ITT or the control group. Average scheduled setpoints are higher during weekends and lower during weekdays as seen by the repeated pattern of peaks and troughs. The ITT group setpoints are noticeably lower relative to the control group during the post tune-up period providing evidence that the SS program is resulting in an adjustment to scheduled heating setpoints, but still follow the peak and trough weekend/weekday pattern.

Figure 4-1. Average Daily Scheduled Setpoint for All Thermostats (Control vs. ITT)



Source: Navigant analysis of Nest thermostat telemetry data

Like Figure 4-1, Figure 4-2 shows average scheduled heating setpoints across all days for the ITT group relative to the control group. Unlike Figure 4-1 it instead shows the difference between those two groups. The reduction in average scheduled heating setpoints for the ITT group during the tune-up period and maintained through the post tune-up period is even more evident in this Figure.

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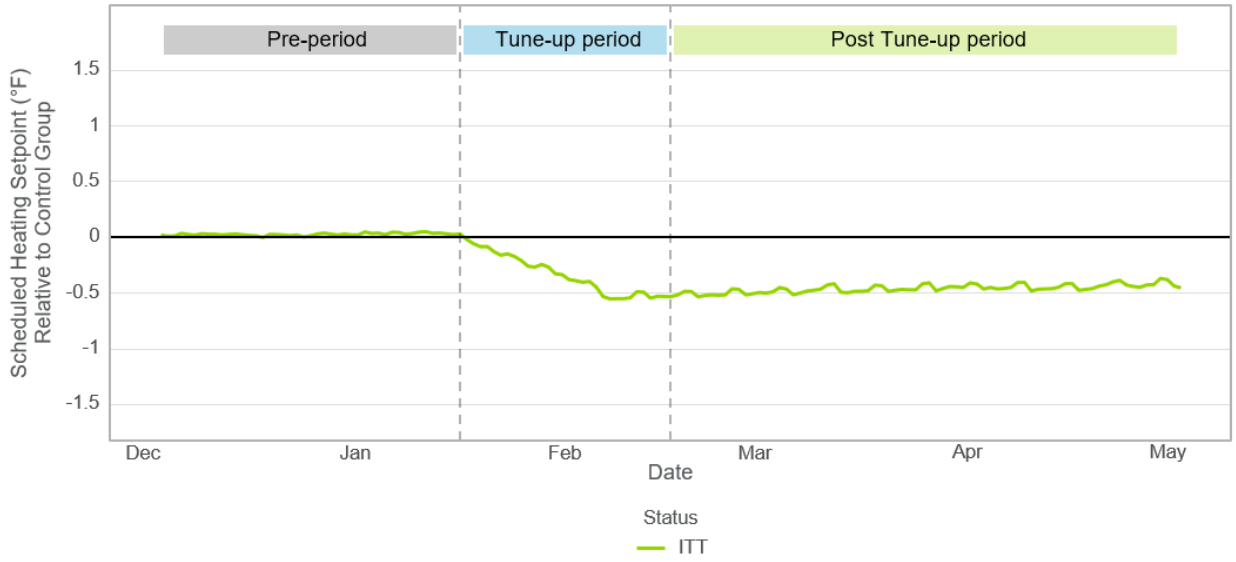
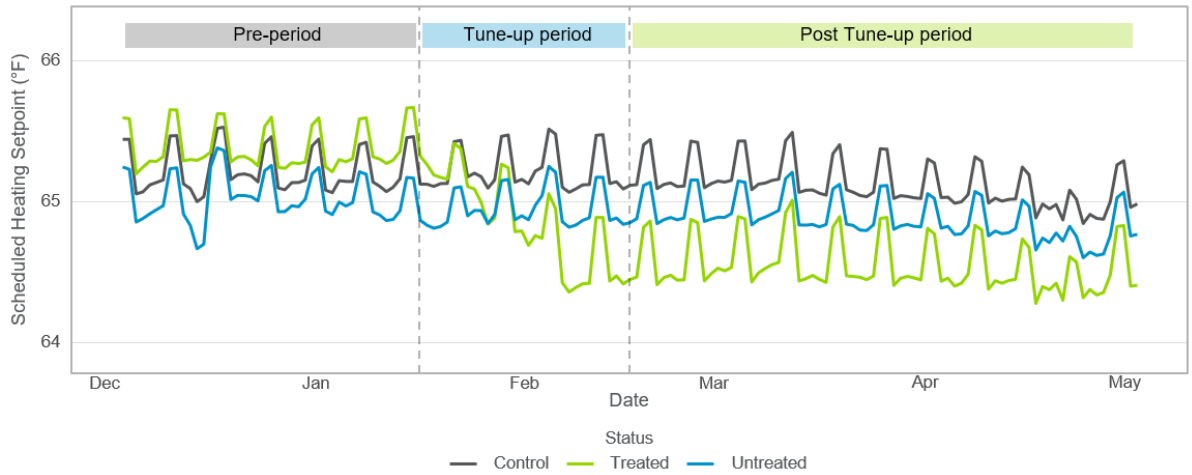
Figure 4-2. Average Daily Scheduled Setpoint Comparison: ITT vs. Control



Source: Navigant analysis of Nest thermostat telemetry data

Figure 4-3 shows average scheduled heating setpoints across all days for the ITT subgroups (treated and untreated) and for the control group. During the pre-period, the treated group has higher average setpoints relative to the control group, while the untreated group has lower average setpoints. The pre-period differences may stem from characteristics correlated with the SS qualification (e.g., connectivity, occupancy, or mode). During the post tune-up period, the untreated and control groups maintain relatively stable average setpoint schedules, having experienced no SS tune-up. In contrast, the treated group setpoints shift down, now the lowest average scheduled setpoints of the three groups.

Figure 4-3. Average Daily Scheduled Setpoint for All Thermostats (Control vs. Treated vs. Untreated)



Source: Navigant analysis of Nest thermostat telemetry data

Figure 4-4 shows average scheduled heating setpoints across all days for the ITT subgroups (treated and untreated) relative to the control group. This is the same information as Figure 4-3 but instead shows the difference between the treated and control groups as well as between the untreated and control groups.

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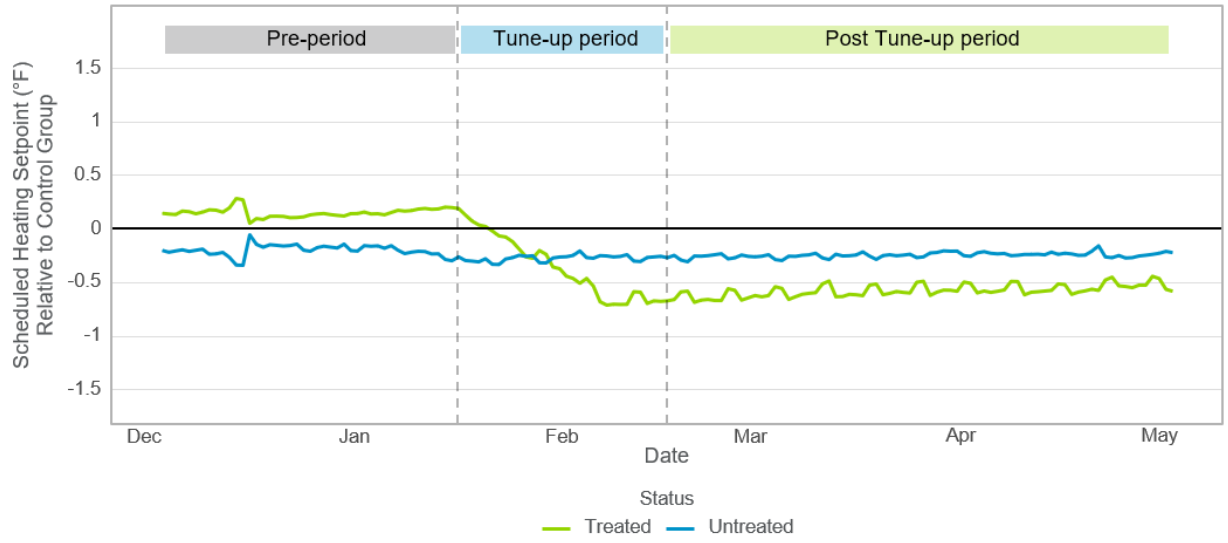
Figure 4-4. Average Daily Scheduled Setpoint Comparison: Treated and Untreated vs. Control



Source: Navigant analysis of Nest thermostat telemetry data

Figure 4-5 and Figure 4-6 show the average daily scheduled setpoints for the natural gas heating and non-natural gas heating segments, respectively. Both groups exhibit a downward shift in average daily setpoint for the ITT group post-deployment. However, the average daily setpoints for the natural gas segment are almost one degree higher relative to the non-natural gas segment. One hypothesis for this difference is the cost of the heating fuel; natural gas is less expensive than electric, oil, or propane heat. A higher average scheduled setpoint may provide the SS algorithm more room for adjustment: treated thermostats in the natural gas segment experienced an average downward shift in setpoints 0.75°F, while treated thermostats in the non-natural gas segment only shifted down 0.70°F. Setpoint summaries by evaluation segment can be found in Appendix A.

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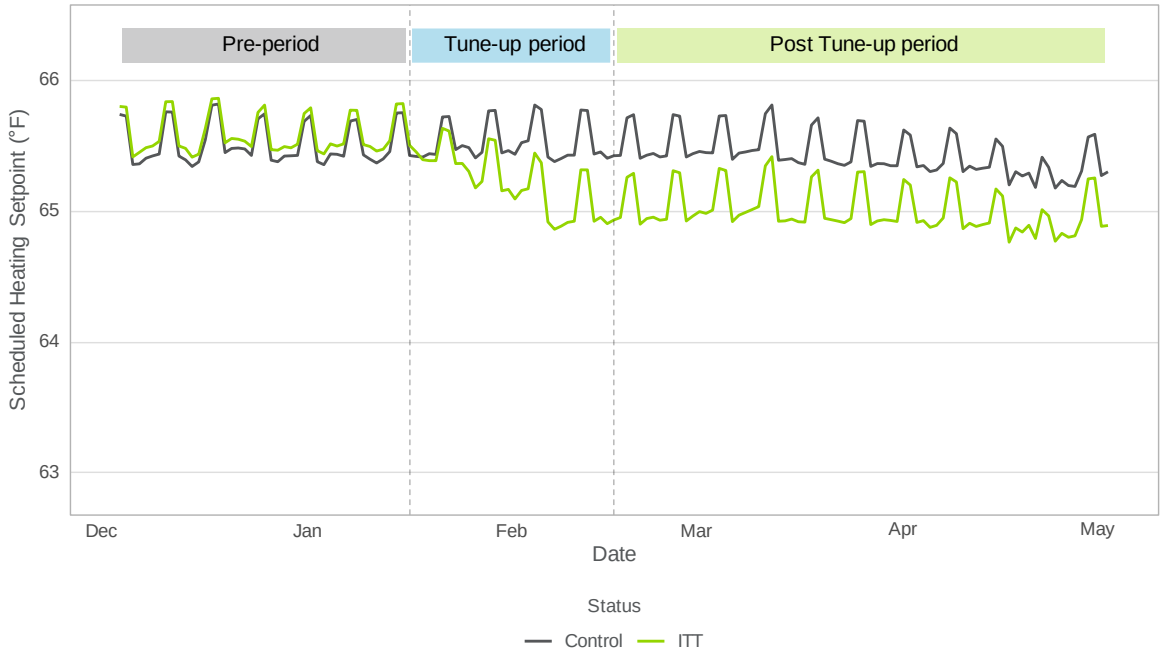
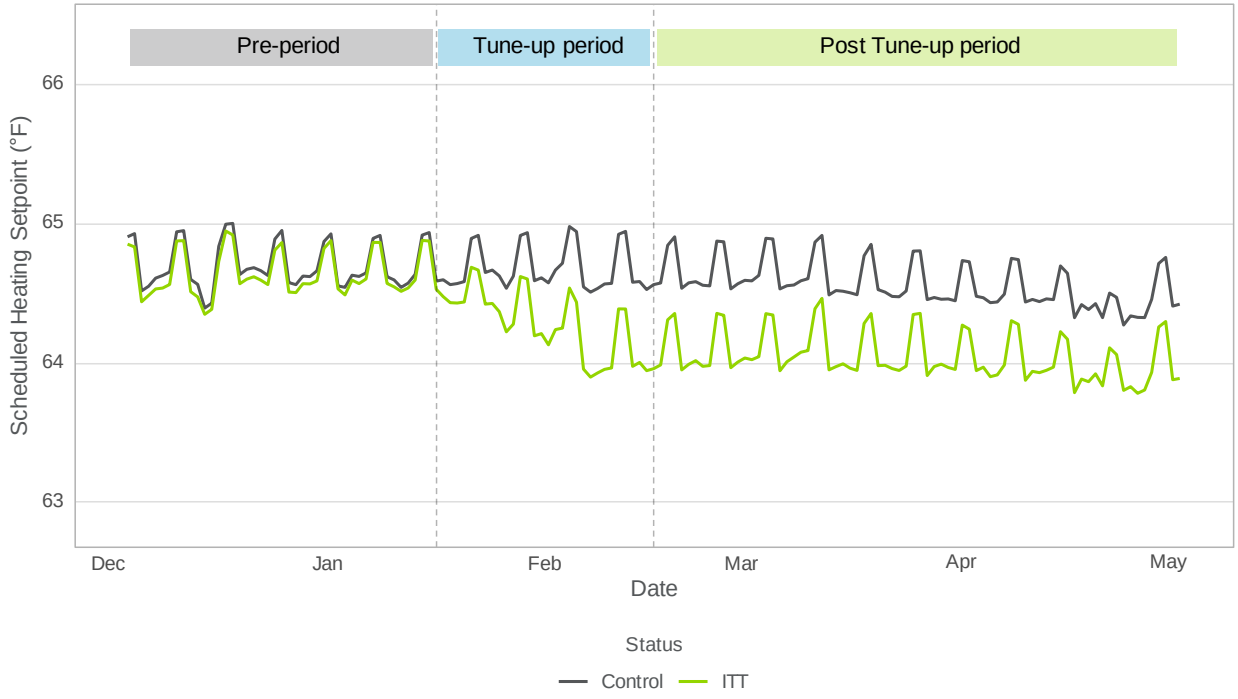
Figure 4-5. Average Daily Scheduled Setpoint – Gas-All (Control vs. ITT)



Source: Navigant analysis of Nest thermostat telemetry data

Figure 4-6. Average Daily Scheduled Setpoint – Non-Gas-All (Control vs. ITT)



Source: Navigant analysis of Nest thermostat telemetry data

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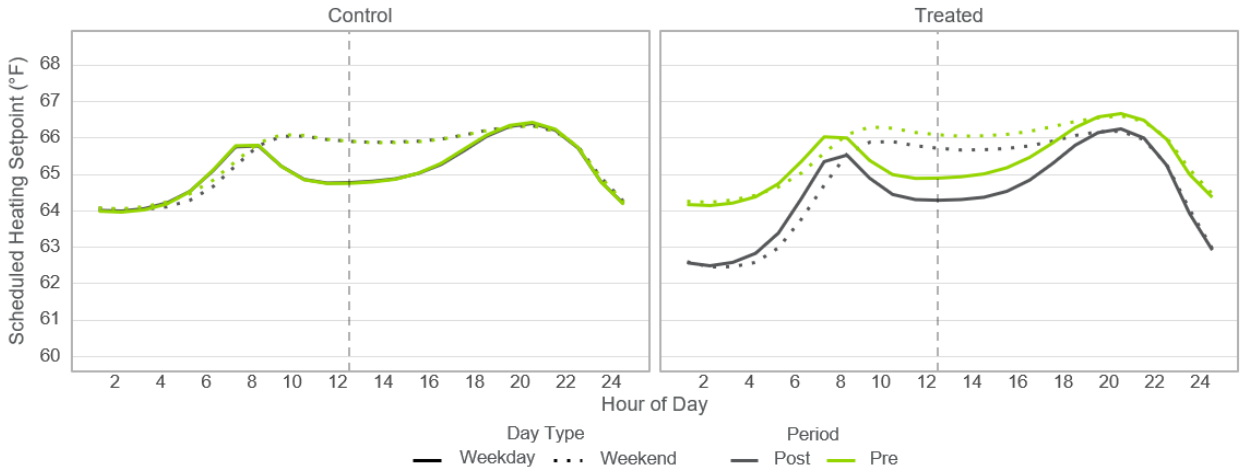
4.1.2 Time Differentiated Analysis

Figure 4-7 presents a comparison of average hourly scheduled heating setpoints for all hours across 2 weeks in 2019 (January 7-13 during the pre-period and February 20-26 during the post period) for both the treated and control groups. The SS program is designed to make the largest adjustments when customers are asleep or away from home (e.g., nighttime, weekday daytime hours) and smaller adjustments when customers are home and awake (e.g., weekday evenings, weekends). Based on the comparisons in Figure 4-7 and the values in Table 4-2, this statement holds. Overall average scheduled heating setpoints decreased by 1.40°F between 11 p.m. and 7 a.m. and 0.56°F during all other hours during the post period week for the treated group relative to control. This pattern is different from the previous summer deployments of SS where the biggest adjustments happened during the day when customers were typically at work.

Figure 4-7. Scheduled Setpoint by Time of Day



Source: Navigant analysis of Nest thermostat telemetry data

Table 4-2. details a breakdown of differences by day type and time of day between the control and treated groups.

Table 4-2. Change in Scheduled Setpoints, Before and After Tune-Up†

Day Type and Period	Treated Change (°F)	Control Change (°F)	Δ‡
Weekday (11 p.m.–7 a.m.)	-1.37	0.01	-1.38
Weekday (Other Hours)	-0.60	-0.00	-0.60
Weekend (11 p.m.–7 a.m.)	-1.55	-0.10	-1.45
Weekend (Other Hours)	-0.47	-0.01	-0.46
Overall (11 p.m.–7 a.m.)	**-1.42**	**-0.02**	**-1.40**
Overall (Other Hours)	**-0.57**	**-0.01**	**-0.56**

† Data shows hourly mean setpoint averages for two distinct weeks during the study: the week before SS began (January 7-13), and one week after the tune-up period (February 20-26)

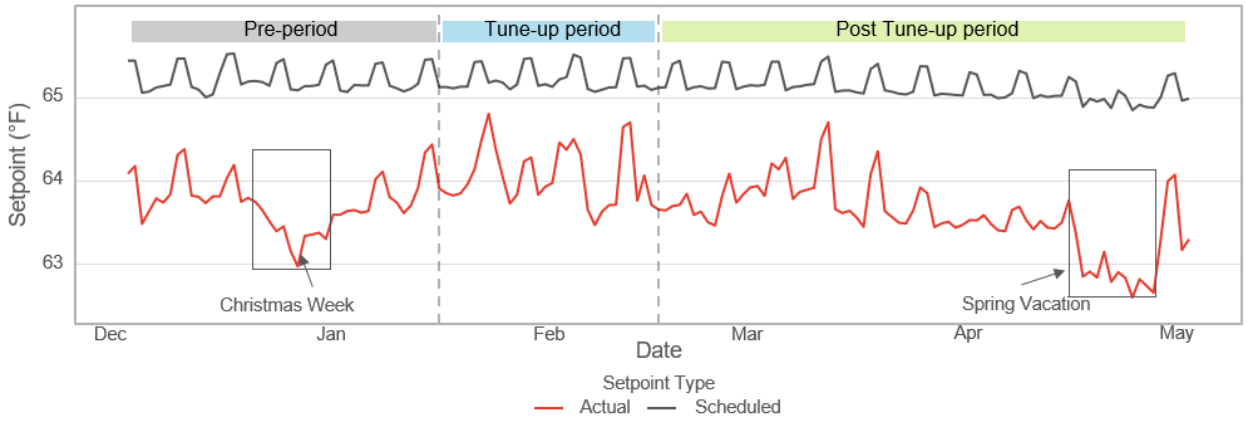
‡ Treated difference minus control difference. Values in table may not compute due to rounding.

Source: Navigant analysis of Nest thermostat telemetry data

4.1.3 Additional Analysis

Figure 4-8 and Table 4-3 show the actual setpoints versus the scheduled setpoints for the control group. The actual setpoints are the setpoints that dictate the temperature the home is heated to. Actual setpoints can differ from the setpoint schedule when customers make manual adjustments to their thermostat or if customers have occupancy detection activated. During the winter 2018-2019 deployment period, the actual setpoints were more than one degree lower on average than the scheduled setpoints for the duration of the winter period; this difference is likely due to the Home/Away Assist feature of the thermostats, which uses activity sensors in Nest products and customers' phone locations to automatically override the thermostat schedule when a customer leaves their home.[11] The boxes in Figure 4-8 show periods where the effect of the Home/Away Assist feature is more pronounced, likely because customers are more likely to be away from their homes during holiday periods.

Figure 4-8. Actual vs. Scheduled Setpoints - Control Group



Source: Navigant analysis of Nest thermostat telemetry data

Table 4-3 shows the average of actual versus scheduled setpoints—and the difference between the two setpoints—for the control group. There is not a significant difference in the actual setpoint, scheduled setpoint, or the difference between them from the pre-tune-up period to the post tune-up period.

Table 4-3. Average of Actual vs. Scheduled Setpoints – Control Group

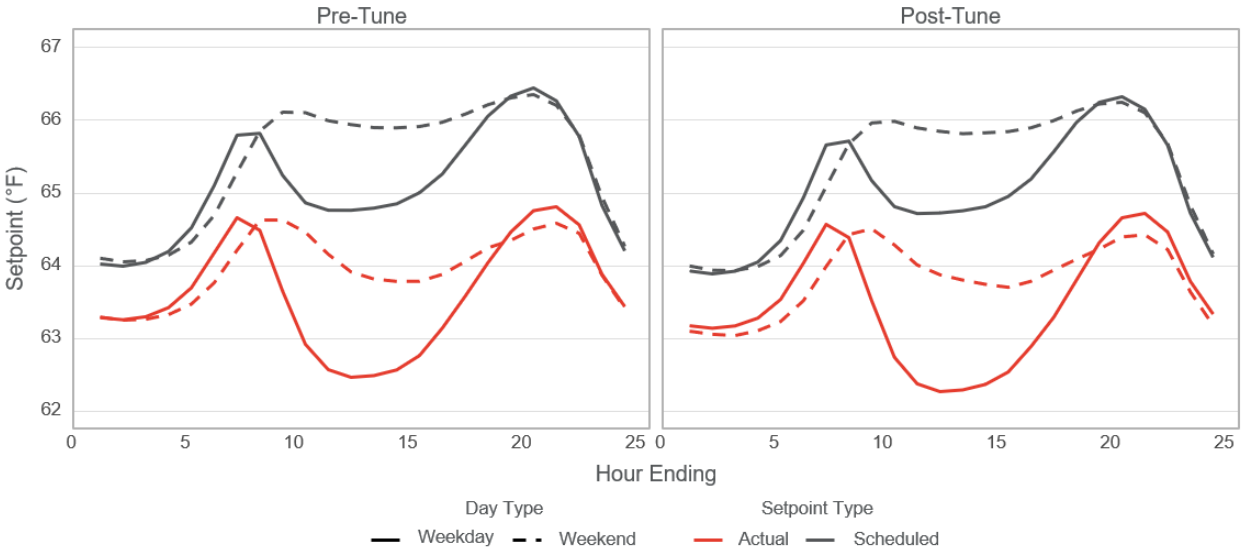
Setpoint Type	Pre-Period Average (°F)	Tune-Up Average (°F)	Post Tune-Up Average (°F)
Scheduled	65.23	65.22	65.13
Actual	63.74	64.04	63.57
Delta	1.49	1.18	1.59

Source: Navigant analysis of Nest thermostat telemetry data

[11] "Learn more about Home/Away Assist." Google. https://support.google.com/googlenest/answer/9257400.

Figure 4-9 shows the actual versus scheduled setpoints by hour of day for the control group. There are no significant differences in actual or scheduled setpoints between the pre-tune and post-tune periods.

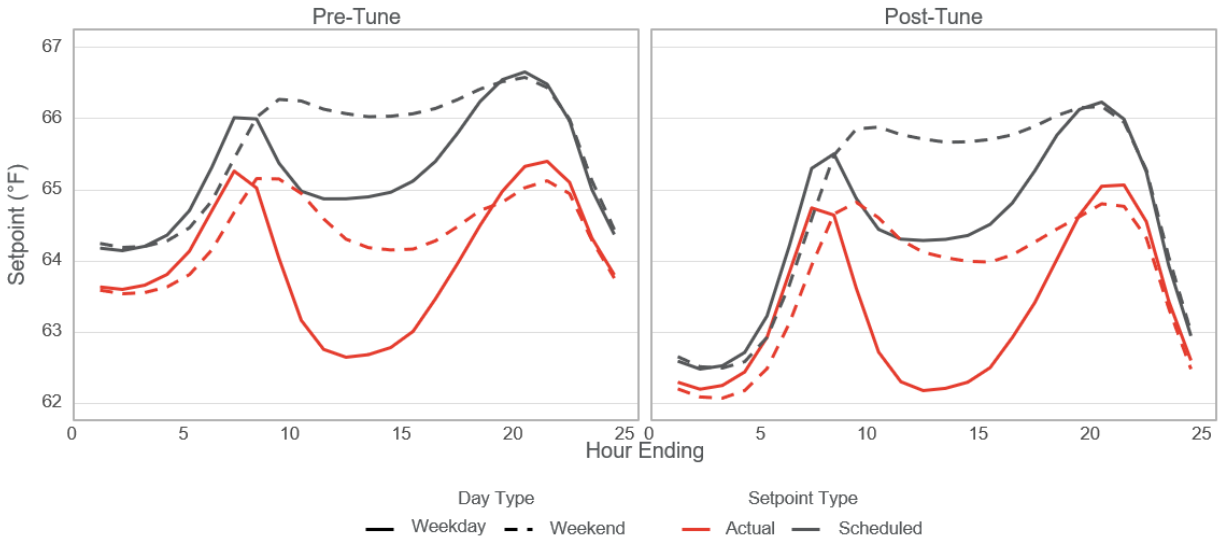
Figure 4-9. Actual vs. Scheduled Setpoints by Hour of Day – Control Group



Source: Navigant analysis of Nest thermostat telemetry data

Figure 4-10 shows the actual versus scheduled setpoints by hour of day for the treated group. The winter SS program reduced both the scheduled and actual setpoints during the post tune-up period.

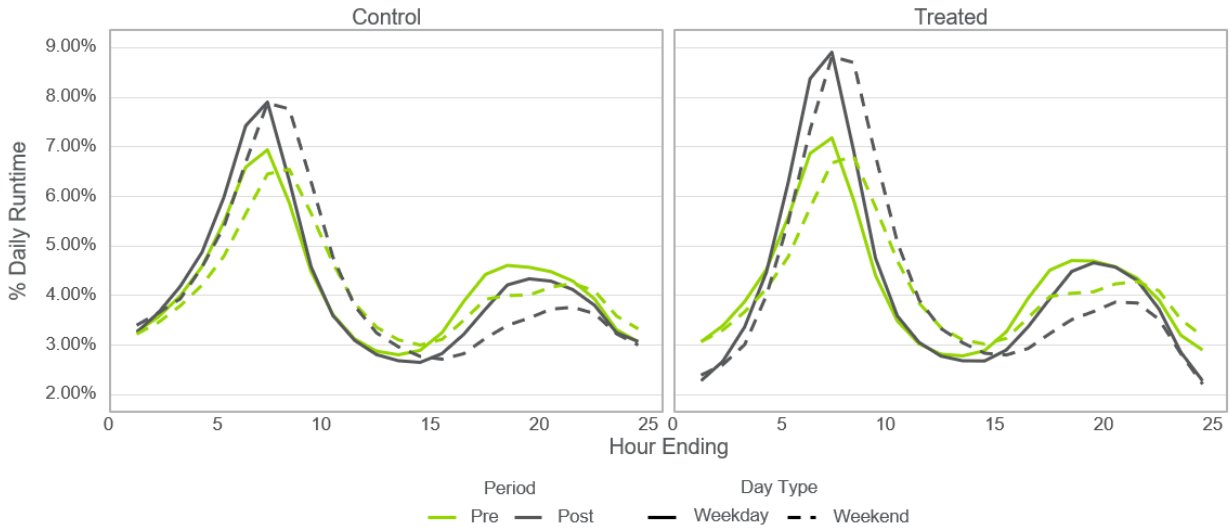
Figure 4-10. Actual vs. Scheduled Setpoints by Hour of Day – Treated Group



Source: Navigant analysis of Nest thermostat telemetry data

Figure 4-11 shows the percent of daily heating runtime by hour of day for the pre-tune and post-tune periods in the control and treated groups. Both the control and treated groups showed a shift of heating runtime load to earlier in the day during the post-tune up period. However, the treated group had a larger shift (as well as an additional downward shift) overnight. This larger shift is likely compensating for the lower overnight heating runtime.

Figure 4-11. Percent Daily Runtime by Hour of Day



Source: Navigant analysis of Nest thermostat telemetry data

4.2 Impact Analysis

Section 4.2 presents findings from the impact analysis. It reports energy and demand savings across all segments and for thermostats with natural gas and other heating fuel types. Key findings include:

- The 2018-2019 winter SS program resulted in total energy savings of 68,684 MMBtu and 559 MWh. A breakout of savings by PA and fuel type is provided later in this section.
- Off-peak savings, as a percent of baseline consumption, were almost three times higher than on-peak savings for both the natural gas and non-natural gas segments.
- The demand savings results were inconclusive as the program tune-up began just under three weeks prior to the end of the winter demand period (January 31).
- Realization rates of 98% for Natural Gas heating fuel savings, 98% for Natural Gas heating electric savings, 99% for Non-Natural Gas heating fuel savings, and 104% for Non-Natural Gas heating electric savings.

4.2.1 Energy and Demand Savings

This section presents the findings from the energy and peak demand impact analyses, summarized in Table 4-4 and Table 4-5.

4.2.1.1 Energy Savings

The SS program resulted in total energy savings of 67,600 MMBtu and 557 MWh from January 14 through April 30, 2019. Average daily energy savings were estimated to be 13.6 therms and 10.7 kWh per treated thermostat, or approximately 4.2% of the heating load for treated thermostats post program launch. Table 4-4 summarizes these findings for all devices and by primary heating fuel type.

Table 4-4. Energy Savings Overview

Primary Heating Fuel	Number of Treated Thermostats	Therm Savings Per Treated Thermostat	Percent Therm Savings	Total MMBtu Savings	kWh Savings per Treated Thermostat	Percent kWh Savings	Total MWh Savings
Natural Gas	34,473	15.5	4.7%	53,564	7.3	4.6%	252
Non-Natural Gas	17,758†	9.5	2.8%	15,120	17.3	6.2%	307
All	**52,231**	**13.6**	**4.1%**	**68,684**	**10.7**	**5.1%**	**559**

† Only 16,006 treated thermostats have fuel-fired heat and therefore receive non-electric fuel savings
Source: Navigant analysis

Navigant estimated energy savings for five different periods between January 14 and April 30, 2019. Energy savings for each period are detailed in Table 4-5 for the natural gas heating segment, and Table 4-6 for the non-natural gas heating segment. Percent savings for the natural gas heating segment are consistent across fuel and electric savings. As expected, savings during the tune-up period are lower than during the post tune-up, when the full setpoint adjustment has taken effect. For the non-natural gas heating segment, percent electric savings are markedly higher than the percent fuel savings. This stems from the fact that the non-natural gas segment includes electric heating from heat pumps and electric resistance heaters. When modeled as its own segment, electric heating savings were almost 10% (see Appendix C for evaluation sub-segment results).

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Table 4-5. Winter Energy Savings Summary: Natural Gas Heating†

Statistic	Fuel Savings (Therms)	Electric Savings (kWh)
Number of Nest thermostats in control group	27,378	
Number of Nest thermostats in ITT group	63,884	
Number of Nest thermostats in treated group	**34,473**	
Winter (Jan 14 – Apr 30) ‡		
Average daily energy savings per-thermostat	0.149 ± 0.023	0.070 ± 0.011
Average energy savings (% of heating load)	4.7% ± 0.7%	4.6% ± 0.7%
Average total energy savings per-thermostat	15.5 ± 2.4	7.3 ± 1.2
Total energy savings (in thousands)	536	252
Tune-Up Period (Jan 14 – Feb 13)		
Average daily energy savings per thermostat	0.117 ± 0.025	0.058 ± 0.012
Average energy savings (% of heating load)	2.6% ± 0.6%	2.7% ± 0.6%
Average total energy savings per thermostat	3.6 ± 0.8	1.8 ± 0.4
Total energy savings (in thousands)	125	62
Post Tune-Up Period (Feb 14 – Apr 30)		
Average daily energy savings per thermostat	0.160 ± 0.028	0.074 ± 0.013
Average energy savings (% of heating load)	6.1% ± 1.1%	5.9% ± 1.1%
Average total energy savings per thermostat	12.0 ± 2.1	5.6 ± 1.0
Total energy savings (in thousands)	413	191

† Navigant modeled each period separately; period results are not additive.

‡ The first offer date for the SS program occurred on January 14, 2019. The SS program persists if heating systems are in heating mode. The energy impact evaluation relies on data through April 30, 2019.

§ On-peak hours are all hours from 7 a.m. to 11 p.m. on non-holiday weekdays.

†† Off-peak hours are all hours from 11 p.m. to 7 a.m. on non-holiday weekdays, plus all hours on weekends and holidays.

Note: confidence interval range (indicated by ±) is 90%.

Source: Navigant analysis

Table 4-6. Winter Energy Savings Summary: Non-Natural Gas Heating†

Statistic	Fuel Savings (Therms)	Electric Savings (kWh)
Number of Nest thermostats in control group	14,502	
Number of Nest thermostats in ITT group	33,862	
Number of Nest thermostats in treated group	**17,758‡‡**	
Winter (Jan 14 – Apr 30) ‡		
Average daily energy savings per thermostat	0.090 ± 0.035	0.165 ± 0.089
Average energy savings (% of heating load)	2.8% ± 1.1%	6.2% ± 3.4%
Average total energy savings per thermostat	9.4 ± 3.7	17.3 ± 9.3
Total energy savings (in thousands)	151	307
Tune-Up Period (Jan 14 – Feb 13)		
Average daily energy savings per thermostat	0.09 ± 0.04	0.19 ± 0.12
Average energy savings (% of heating load)	2.0% ± 0.8%	4.7% ± 3.0%
Average total energy savings per thermostat	2.9 ± 1.1	5.7 ± 3.6
Total energy savings (in thousands)	46	102
Post Tune-Up Period (Feb 14 – Apr 30)		
Average daily energy savings per thermostat	0.09 ± 0.04	0.15 ± 0.11
Average energy savings (% of heating load)	3.4% ± 1.6%	7.1% ± 5.3%
Average total energy savings per thermostat	6.7 ± 3.2	11.3 ± 8.4
Total energy savings (in thousands)	107	199

† Navigant modeled each period separately; period results are not additive.

‡ The first offer date for the SS program occurred on January 14, 2019. The SS program persists if heating systems are in heating mode. The energy impact evaluation relies on data through April 30, 2019.

§ On-peak hours are all hours from 7 a.m. to 11 p.m. on non-holiday weekdays.

†† Off-peak hours are all hours from 11 p.m. to 7 a.m. on non-holiday weekdays, plus all hours on weekends and holidays.

‡‡ Only 16,006 treated thermostats have fuel-fired heat and therefore receive non-electric fuel savings

Note: confidence interval range (indicated by ±) is 90%.

Source: Navigant analysis

Table 4-7 and Table 4-8 summarize the winter 2018-2019 SS savings by PA and heating fuel type.

Table 4-7. Natural Gas Heating Savings Summary

PA	Heating Fuel Type	Measure Life	No. of Participating Thermostats	Total MMBtu Savings†	Total MWh Savings†
Eversource	Natural Gas	1	11,662	18,120	85
National Grid	Natural Gas	1	22,811	35,444	167
Statewide	**Natural Gas**	**1**	**34,473**	**53,564**	**252**

† Total savings are calculated using the statewide natural gas per-thermostat savings

Source: Navigant analysis

Table 4-8. Non-Natural Gas Heating Savings Summary

PA	Heating Fuel Type	Measure Life	No. of Participating Thermostats	Total MMBtu Savings†	Total MWh Savings†
Cape Light Compact	Electric	1	41	-	1
	Oil	1	591	558	10
	Propane	1	326	308	6
Eversource	Electric	1	1,302	-	23
	Oil	1	5,912	5,585	102
	Propane	1	1,047	989	18
National Grid	Electric	1	409	-	7
	Oil	1	6,735	6,362	116
	Propane	1	1,395	1,318	24
Statewide	**Non-Natural Gas**	**1**	**17,758**	**15,120**	**307**

† Total savings are calculated using the statewide non-natural gas per-thermostat savings
Source: Navigant analysis

4.2.1.2 Effective Winter Energy Savings

Given the late deployment of the SS program during the 2018-2019 winter, Navigant predicted savings as if the program had deployed December 1 (which would have added an extra 45 days to the deployment period). Estimated savings for the effective winter period are presented in Table 4-9. Navigant estimates an extra 22,000 MMBtu could have been saved for the natural gas heating segment and an extra 10,000 MMBtu for the non-natural gas segment with a December 1 deployment. That is a 42% and 66% percent increase in savings for each respective segment. This predicted increase in savings is based on the additional 45 days of savings and colder than average weather in December 2018 than the actual post-deployment period.

Table 4-9. Effective Winter (Dec 1 – Apr 30) Energy Savings

Heating Fuel Type	Fuel Savings (MMBtu)	Electric Savings (MWh)
Natural Gas	75,866	358
Non-Natural Gas	25,095	441

Source: Navigant analysis

4.2.1.3 Peak Period Energy Savings

Navigant modeled the winter on-peak and off-peak period electric saving for the winter 2018-2019 deployment of SS. The on-peak period is defined as all hours from 7 a.m. to 11 p.m. on non-holiday weekdays. The off-peak period is all other hours. The evaluation found that off-peak savings, as a percent of baseline consumption, were almost three times higher than on-peak savings for both the natural gas and non-natural gas segments. This finding is supported by the fact that the biggest setpoint adjustments take place overnight, falling squarely in the off-peak period. Similar to the full winter electric savings, the percent savings for the non-natural gas segment are higher than for the natural gas segment.

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Table 4-10. Winter Peak Period Energy Savings Summary: Natural Gas Heating

Statistic	Electric Savings (kWh)
Number of Nest thermostats in control group	27,378
Number of Nest thermostats in ITT group	63,884
Number of Nest thermostats in treated group	**34,473**
Winter (Jan 14 – Apr 30) On-Peak † ‡	
Average daily energy savings per-thermostat	0.022 ± 0.008
Average energy savings (% of heating load)	2.3% ± 0.8%
Average total energy savings per thermostat	2.2 ± 0.8
Total energy savings (in thousands)	75
Winter (Jan 14 – Apr 30) Off-Peak §	
Average daily energy savings per thermostat	0.056 ± 0.007
Average energy savings (% of heating load)	6.5% ± 0.8%
Average total energy savings per thermostat	5.8 ± 0.7
Total energy savings (in thousands)	200

† The first offer date for the SS program occurred on January 14, 2019. The SS program persists if heating systems are in heating mode. The energy impact evaluation relies on data through April 30, 2019.

‡ On-peak hours are all hours from 7 a.m. to 11 p.m. on non-holiday weekdays.

§ Off-peak hours are all hours from 11 p.m. to 7 a.m. on non-holiday weekdays, plus all hours on weekends and holidays.

Note: confidence interval range (indicated by ±) is 90%.

Source: Navigant analysis

Table 4-11. Winter Peak Period Energy Savings Summary: Non-Natural Gas Heating

Statistic	Electric Savings (kWh)
Number of Nest thermostats in control group	14,502
Number of Nest thermostats in ITT group	33,862
Number of Nest thermostats in treated group	**17,758**
Winter (Jan 14 – Apr 30) On-Peak † ‡	
Average daily energy savings per thermostat	0.058 ± 0.065
Average energy savings (% of heating load)	3.5% ± 4.0%
Average total energy savings per thermostat	5.8 ± 6.5
Total energy savings (in thousands)	102
Winter (Jan 14 – Apr 30) Off-Peak §	
Average daily energy savings per thermostat	0.122 ± 0.053
Average energy savings (% of heating load)	8.3% ± 3.5%
Average total energy savings per thermostat	12.8 ± 5.5
Total energy savings (in thousands)	227

† The first offer date for the SS program occurred on January 14, 2019. The SS program persists if heating systems are in heating mode. The energy impact evaluation relies on data through April 30, 2019.

‡ On-peak hours are all hours from 7 a.m. to 11 p.m. on non-holiday weekdays.

§ Off-peak hours are all hours from 11 p.m. to 7 a.m. on non-holiday weekdays, plus all hours on weekends and holidays.

Note: confidence interval range (indicated by ±) is 90%.

Source: Navigant analysis

Navigant also estimated peak demand impacts from 5 p.m. to 7 p.m. on program period non-holiday weekdays through January. The results are inconclusive as the demand savings analysis did not produce statistically significant estimates of savings. This is likely due to the late deployment of the SS program, which only overlapped with the winter demand period for just under three weeks.

Table 4-12. 2018-2019 SS Winter Demand Savings Summary: Natural Gas Heating

Statistic	Treated Thermostat Savings
Number of Nest thermostats in control group	27,378
Number of Nest thermostats in ITT group	63,884
Number of Nest thermostats in treated group	**34,473**
Winter (Jan 14 – Jan 31) ‡	
Average demand savings per thermostat (W)	0.15 ± 0.84
Average demand savings (percent of heating load)	0.14% ± 0.77%
Total average demand savings (kW) §	0
Adjusted Winter (Dec 1 – Jan 31) ††	
Total average demand savings (kW) §	0

‡ The first offer date for the SS program occurred on January 14, 2019. The SS program persists if heating systems are in heating mode. The demand impact evaluation relies on data through January 31, 2019.

§ Total demand savings are estimated to be zero as savings at the individual thermostat level were statistically insignificant.

†† Adjusted Winter values are winter values adapted to be from Dec 1, 2018 through January 31, 2019.

Note: confidence interval range (indicated by ±) is 90%.

Source: Navigant analysis

Table 4-13. 2018-2019 SS Winter Demand Savings Summary: Non-Natural Gas Heating

Statistic	Treated Thermostat Savings
Number of Nest thermostats in control group	14,502
Number of Nest thermostats in ITT group	33,862
Number of Nest thermostats in treated group	**17,758**
Winter (Jan 14 – Jan 31) ‡	
Average demand savings per thermostat (W)	3.66 ± 6.63
Average demand savings (percent of heating load)	1.87% ± 3.38%
Total average demand savings (kW) §	0
Adjusted Winter (Dec 1 – Jan 31) ††	
Total average demand savings (kW) §	0

‡ The first offer date for the SS program occurred on January 14, 2019. The SS program persists if heating systems are in heating mode. The demand impact evaluation relies on data through January 31, 2019.

§ Total demand savings are estimated to be zero as savings at the individual thermostat level were statistically insignificant.

†† Adjusted Winter values are winter values adapted to be from Dec 1, 2018 through January 31, 2019.

Note: confidence interval range (indicated by ±) is 90%.

Source: Navigant analysis

4.2.2 Realization Rate

Navigant developed a realization rate for the natural gas and non-natural gas segments, calculated as the ratio of Navigant's savings estimate to the savings reported by Google. These values are shown in Table 4-14 and Table 4-15. All realization rates are close to 100%, but small differences in the modeled energy savings per thermostat led to differing estimates of total energy savings.

Table 4-14. Realization Rates – Natural Gas

Estimation	Navigant	Google	Realization Rate§
Average total energy savings per thermostat (therms)	15.5	15.9	97%
Total energy savings (MMBtu)	53,564	54,788	98%
Average total energy savings per thermostat (kWh)	7.3	7.5	97%
Total energy savings (MWh)	252	257	98%

§ Estimated savings are different between Navigant and Google due to small differences in the modeled savings.
Source: Navigant analysis, Google savings estimates

Table 4-15. Realization Rates – Non-Natural Gas

Estimation	Navigant	Google	Realization Rate§
Average total energy savings per thermostat (therms)	9.5	9.6	99%
Total energy savings (MMBtu)	15,120	15,326	99%
Average total energy savings per thermostat (kWh)	17.3	16.9	102%
Total energy savings (MWh)	307	296	104%

§ Estimated savings are different between Navigant and Google due to small differences in the modeled savings.
Source: Navigant analysis, Google savings estimates

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5. FINDINGS AND RECOMMENDATIONS

Navigant's evaluation found the SS program for winter 2018-2019 was successful in achieving energy savings through temperature optimization and in customer acceptance of the offering. The evaluation shows that temperature optimization is an effective tool for realizing energy savings; however, further research is warranted regarding incremental savings from future deployments and persistence of savings, the stability of the realization rate, and refinements to the runtime to energy conversion. Table 5-1 summarizes the key evaluation findings, Table 5-2 provides recommendations.

Table 5-1. Key Findings

Key Findings
• Over half of thermostats in the ITT group opted in to the program — 53%.
• The heating setpoint schedules for the treated thermostats were adjusted downward during the program period — 0.73°F.
• The largest setpoint adjustments took place during the middle of the night, when customers were likely to asleep — 1.50°F. This is different than the 2018 summer SS program which saw the largest adjustments during the middle of the weekdays.
• The average energy savings per treated thermostat between January 14, 2019 and April 30, 2019 were 13.6 therms and 10.7 kWh.
• The program yielded average energy savings of 4.1% of fuel heating load and 5.1% of electric heating load between January 14, 2019 and April 30, 2019.
• The program yielded no statistically significant peak demand savings between January 14, 2019 and January 31, 2019
• The program achieved energy savings between January 14, 2019 and April 30, 2019 of 68,684 MMBtu and 559 MWh.
• Compared to vendor reported savings, the program achieved 98% of Natural Gas heating fuel savings, 98% of Natural Gas heating electric savings, 99% for Non-Natural Gas heating fuel savings, and 104% for Non-Natural Gas heating electric savings

Source: Navigant analysis

Table 5-2. Recommendations

Topic	Recommendations

Savings	• For the current 2018-2019 winter season, the Massachusetts PA should use a realization rate of:
	  ○ 97% for Natural Gas heating fuel savings
	  ○ 98% for Natural Gas heating electric savings
	  ○ 98% for Non-Natural Gas (Oil and Propane) heating fuel savings
	  ○ 100% for Non-Natural Gas (Electric, Oil, and Propane) heating electric savings
	• These realization rates can be applied to the vendor reported estimates of total savings or per-thermostat savings.

Source: Navigant

Table 5-3. Considerations

Topic	Considerations

Realization Rate	• For the future winter seasons where SS is deployed, the Massachusetts PA can use a realization rate of:
	  ○ 97% for Natural Gas heating fuel savings
	  ○ 98% for Natural Gas heating electric savings
	  ○ 98% for Non-Natural Gas (Oil and Propane) heating fuel savings
	  ○ 100% for Non-Natural Gas (Electric, Oil, and Propane) heating electric savings
	• If these realization rates are used for future deployments, the vendor (Google) should estimate savings of therms and kWh using a two-way fixed effects model and a Natural Gas/Non-Natural Gas segmentation.
	• For winter 2019-2020, evaluate the SS program to better inform a realization rate for inclusion in the Technical Reference Manual.

Runtime to Energy	• The PAs should seek to improve the runtime to energy estimates by developing an estimate of natural gas space heating consumption per thermostat for homes with furnaces or with boilers. This would be combined with the total thermostat runtime to update the runtime to energy estimates.

Source: Navigant

APPENDIX A. EXPLORATORY ANALYSIS – SETPOINTS BY SUB-SEGMENT

A.1 Setpoint Summary

Table A-1 shows a summary of setpoint reduction for each sub-segment evaluated. This table presents setpoint reduction in terms of both absolute reduction and percent reduction.

Table A-1. Summary of Setpoint Reduction for All Sub-Segments

Evaluation Segment	Treated Devices	Pre-SP (°F)	SP Reduction (°F)	% SP Reduction
All	**52,238**	**65.4**	**-0.73**	**-1.12%**
Gas-All	**34,480**	**65.7**	**-0.75**	**-1.14%**
Gas-NGrid	22,813	65.5	-0.75	-1.15%
Gas-EVS	11,667	66.0	-0.76	-1.15%
Non-Gas-All	**17,758**	**64.8**	**-0.70**	**-1.08%**
Oil-All	13,238	64.6	-0.72	-1.11%
Oil-NGrid	6,735	64.5	-0.74	-1.14%
Oil-EVS	5,912	64.7	-0.73	-1.13%
Oil-CLC	591	63.6	-0.59	-0.93%
Propane-All	2,768	64.8	-0.59	-0.91%
Electric-All	1,752	66.9	-0.83	-1.24%

Source: Navigant analysis of Nest thermostat telemetry data

A.2 Setpoint Summary by PA and Fuel Type

Table A-2 through Table A-11 provide the average daily scheduled heating setpoints for the control, ITT, and treated and untreated subgroups for each sub-segment analyzed. The exploratory analysis compares the scheduled heating setpoints between the pre-period and post tune-up period for each group. The analysis found that the SS program made the intended adjustments to scheduled heating setpoints in each sub-segment analyzed. The reduction in average daily scheduled heating setpoints (from pre tune-up to post tune-up) is greater for the treated group than the control group in each sub-segment.

Treated devices in the natural gas heating segment showed similar scheduled setpoint reductions relative to control across both PAs as seen in Table A-2 and Table A-3. National Grid devices showed a 0.75º F reduction while Eversource devices showed a 0.76º F reduction.

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Table A-2. Summary of Exploratory Setpoint Analysis – Gas – National Grid

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.22	40.34	6.11	-
Average Daily Scheduled Heating Setpoints (°F)	Control	65.32	65.22	-0.10	-
	Intent-to-Treat	65.38	64.78	-0.60	-0.50
	Treated	65.53	64.68	-0.85	-0.75
	Untreated	65.13	64.95	-0.18	-0.08

Source: Navigant analysis of Nest thermostat telemetry data

Table A-3. Summary of Exploratory Setpoint Analysis – Gas – Eversource

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.78	40.05	6.26	-
Average Daily Scheduled Heating Setpoints (°F)	Control	65.90	65.85	-0.05	-
	Intent-to-Treat	66.01	65.47	-0.54	-0.49
	Treated	65.98	65.18	-0.81	-0.76
	Untreated	66.06	66.05	-0.01	0.04

Source: Navigant analysis of Nest thermostat telemetry data

Overall, treated devices in the natural gas heating segment reduced their scheduled setpoint by 0.75º F on average in the post tune-up period relative to control, as shown in Table A-4.

Table A-4. Summary of Exploratory Setpoint Analysis – Gas – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.40	40.57	6.16	-
Average Daily Scheduled Heating Setpoints (°F)	Control	65.51	65.43	-0.08	-
	Intent-to-Treat	65.59	65.00	-0.58	-0.50
	Treated	65.68	64.85	-0.83	-0.75
	Untreated	65.41	65.28	-0.13	-0.05

Source: Navigant analysis of Nest thermostat telemetry data

As seen in Table A-5 through Table A-7, treated devices in the oil heating segment showed a smaller scheduled setpoint reduction relative to control for Cape Light Compact than for National Grid and Eversource. Cape Light Compact devices showed a 0.59º F reduction while National Grid devices showed a 0.74º F reduction and Eversource devices showed a 0.73º F reduction. Cape Light Compact also had the smallest sample size with 591 treated devices vs. 6,735 for National Grid and 5,912 for Eversource.

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Table A-5. Summary of Exploratory Setpoint Analysis – Oil – National Grid

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		32.92	39.43	6.50	-
Average Daily Scheduled Heating Setpoints (°F)	Control	64.50	64.49	-0.01	-
	Intent-to-Treat	64.46	63.98	-0.48	-0.47
	Treated	64.52	63.77	-0.75	-0.74
	Untreated	64.36	64.36	0.00	0.01

Source: Navigant analysis of Nest thermostat telemetry data

Table A-6. Summary of Exploratory Setpoint Analysis – Oil – Eversource

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.18	40.64	6.46	-
Average Daily Scheduled Heating Setpoints (°F)	Control	64.77	64.65	-0.11	-
	Intent-to-Treat	64.67	64.06	-0.60	-0.49
	Treated	64.72	63.88	-0.84	-0.73
	Untreated	64.56	64.44	-0.12	-0.01

Source: Navigant analysis of Nest thermostat telemetry data

Table A-7. Summary of Exploratory Setpoint Analysis – Oil – Cape Light Compact

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		35.84	40.05	4.21	-
Average Daily Scheduled Heating Setpoints (°F)	Control	62.62	62.32	-0.30	-
	Intent-to-Treat	62.66	61.97	-0.70	-0.40
	Treated	63.55	62.67	-0.88	-0.59
	Untreated	61.86	61.36	-0.50	-0.20

Source: Navigant analysis of Nest thermostat telemetry data

Overall, treated devices in the oil heating segment reduced their scheduled setpoint by 0.72º F on average in the post tune-up period relative to control, as shown in Table A-8.

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Table A-8. Summary of Exploratory Setpoint Analysis – Oil – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		33.67	39.99	6.32	-
Average Daily Scheduled Heating Setpoints (°F)	Control	64.50	64.42	-0.08	-
	Intent-to-Treat	64.44	63.89	-0.55	-0.48
	Treated	64.57	63.77	-0.80	-0.72
	Untreated	64.22	64.11	-0.11	-0.03

Source: Navigant analysis of Nest thermostat telemetry data

As shown in Table A-9, treated devices in the propane heating segment reduced their scheduled setpoint by the smallest amount relative to control among fuel types in the study. These devices showed a 0.59º F reduction.

Table A-9. Summary of Exploratory Setpoint Analysis – Propane – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.12	39.88	5.76	-
Average Daily Scheduled Heating Setpoints (°F)	Control	64.19	63.89	-0.30	-
	Intent-to-Treat	64.19	63.52	-0.67	-0.38
	Treated	64.80	63.91	-0.89	-0.59
	Untreated	63.32	62.97	-0.35	-0.05

Source: Navigant analysis of Nest thermostat telemetry data

Treated devices in the electric heating segment reduced their scheduled setpoint by the largest amount relative to control among fuel types in the study, shown in Table A-10. These devices showed a 0.83º F reduction. These devices also had the highest pre-period setpoint at 66.9º F.

Table A-10. Summary of Exploratory Setpoint Analysis – Electric – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		35.45	41.48	6.04	-
Average Daily Scheduled Heating Setpoints (°F)	Control	67.07	66.85	-0.22	-
	Intent-to-Treat	66.89	66.17	-0.72	-0.49
	Treated	66.93	65.88	-1.05	-0.83
	Untreated	66.83	66.59	-0.24	-0.02

Source: Navigant analysis of Nest thermostat telemetry data

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Overall, treated devices in the non-gas heating segment reduced their scheduled setpoints by 0.70º F on average in the post tune-up period relative to control, shown in Table A-11. This was a smaller reduction than devices in the gas heating segment (0.75º F reduction).

Table A-11. Summary of Exploratory Setpoint Analysis – Non-Gas – All PAs

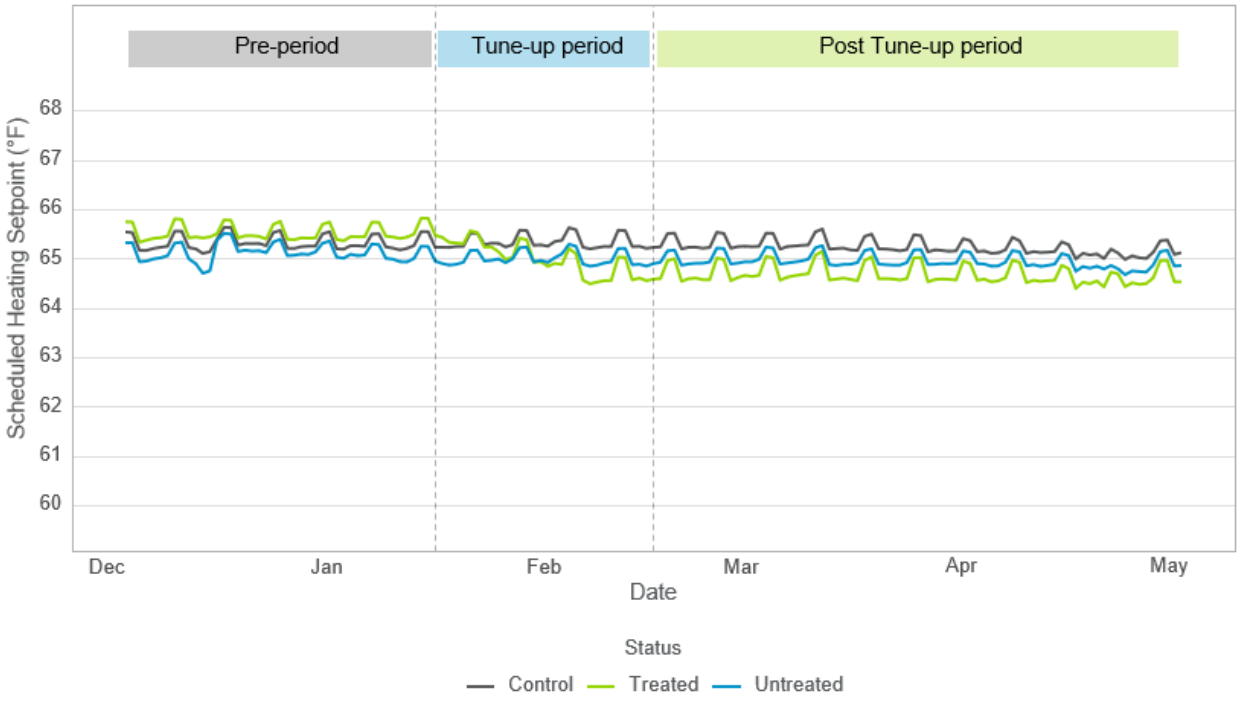
Group		Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		33.95	40.14	6.19	-
Average Daily Scheduled Heating Setpoints (°F)	Control	64.70	64.56	-0.14	-
	Intent-to-Treat	64.64	64.04	-0.60	-0.46
	Treated	64.82	63.98	-0.84	-0.70
	Untreated	64.34	64.15	-0.18	-0.04

Source: Navigant analysis of Nest thermostat telemetry data

A.3 Setpoint Summary Graphics

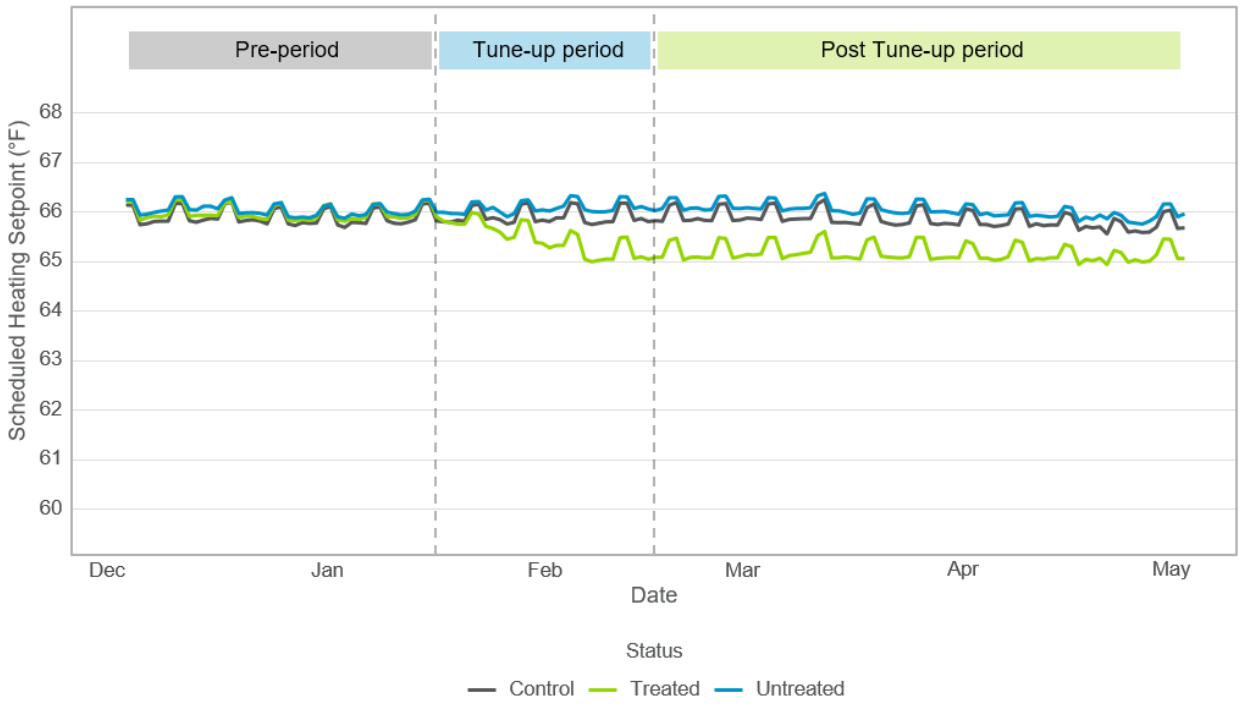
Figure A-1 through Figure A-9 show average scheduled heating setpoints across all days for the ITT subgroups (treated and untreated) and the control group for each sub-segment analyzed. In the pre-period, the figures show that the treated groups typically have average setpoints that are higher than or approximately equal to the control groups. During the post tune-up period, the untreated and control groups maintain relatively stable average scheduled setpoints, having experienced no SS tune-up. In contrast, the treated group setpoints shift down.

Figure A-1. Daily Scheduled Setpoints – Gas – National Grid



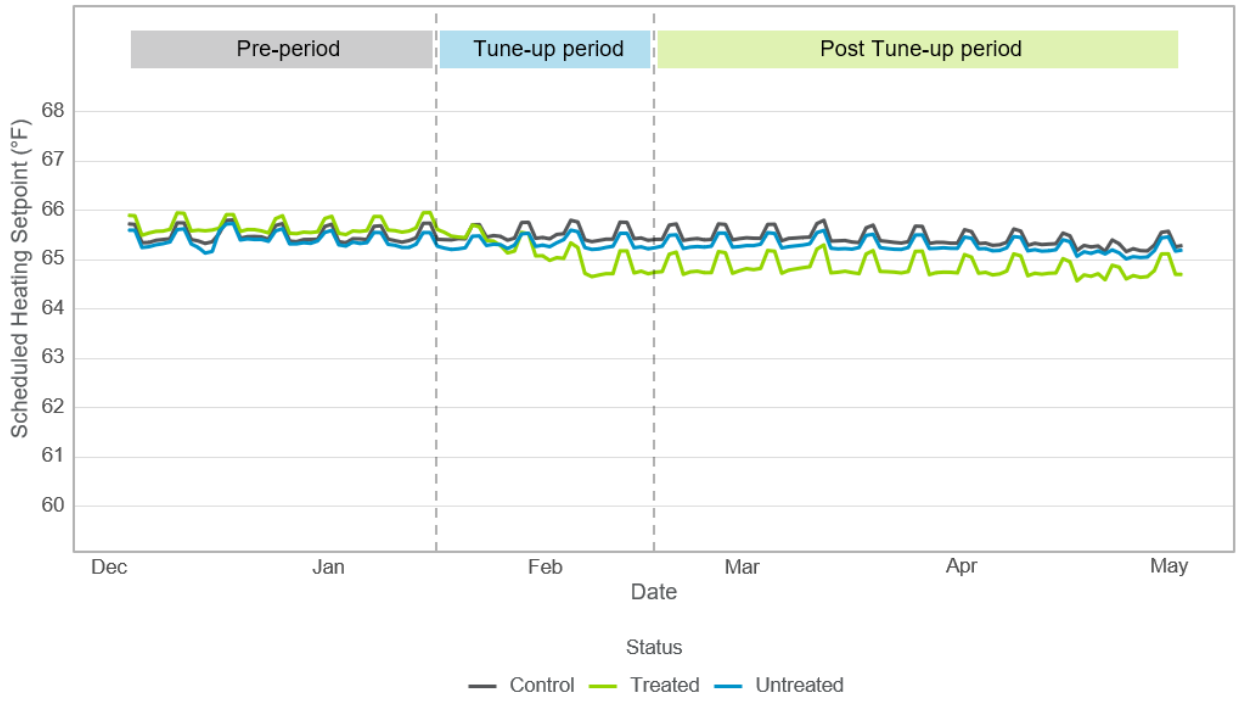
Source: Navigant analysis of Nest thermostat telemetry data

Figure A-2. Daily Scheduled Setpoints – Gas – Eversource



Source: Navigant analysis of Nest thermostat telemetry data

Figure A-3. Daily Scheduled Setpoints – Gas – All



Source: Navigant analysis of Nest thermostat telemetry data

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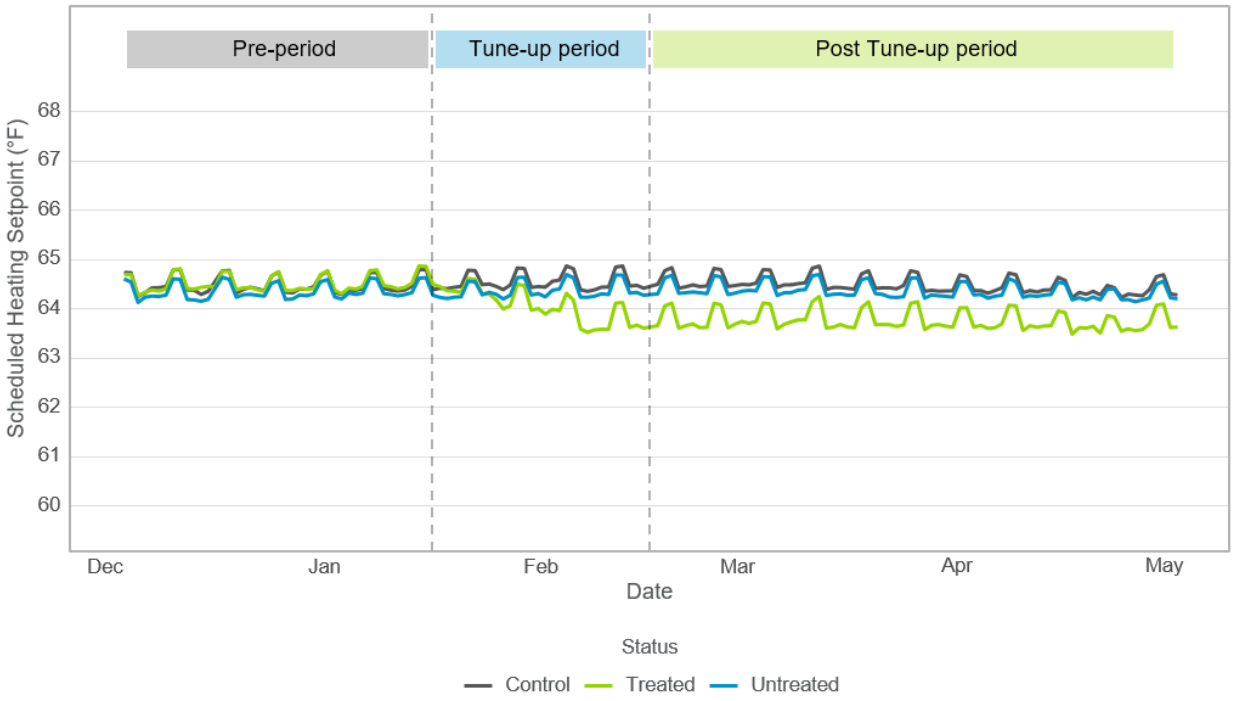
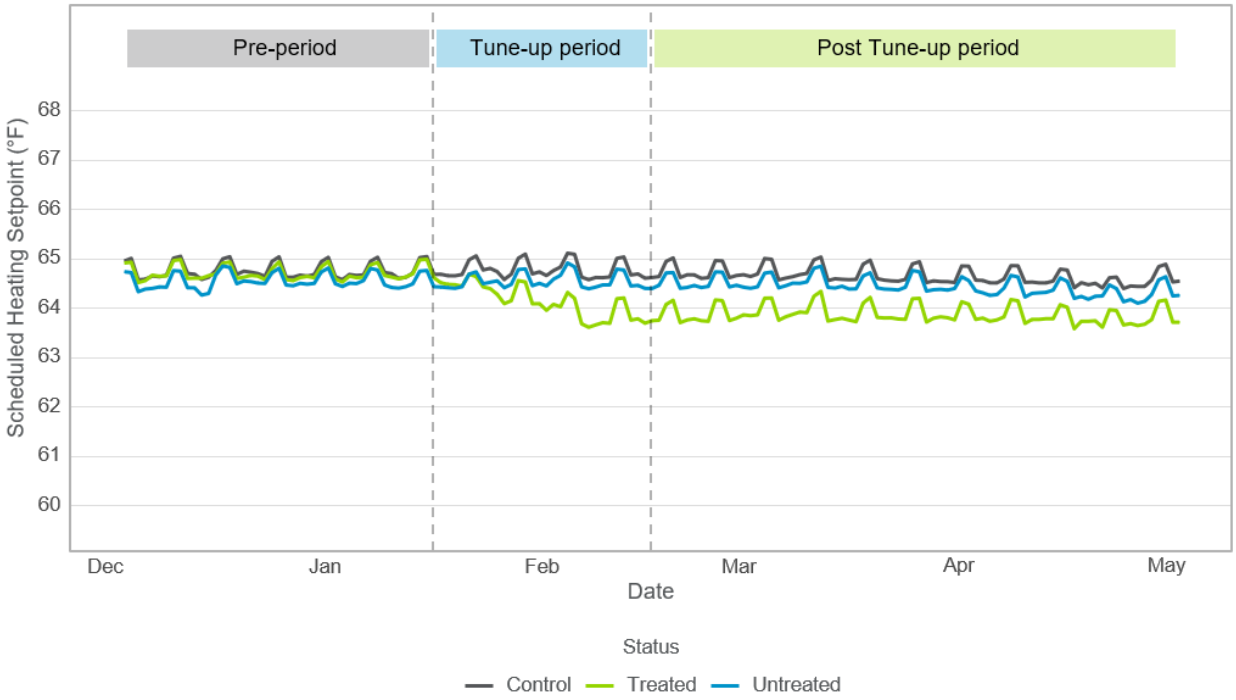
Figure A-4. Daily Scheduled Setpoints – Oil – National Grid



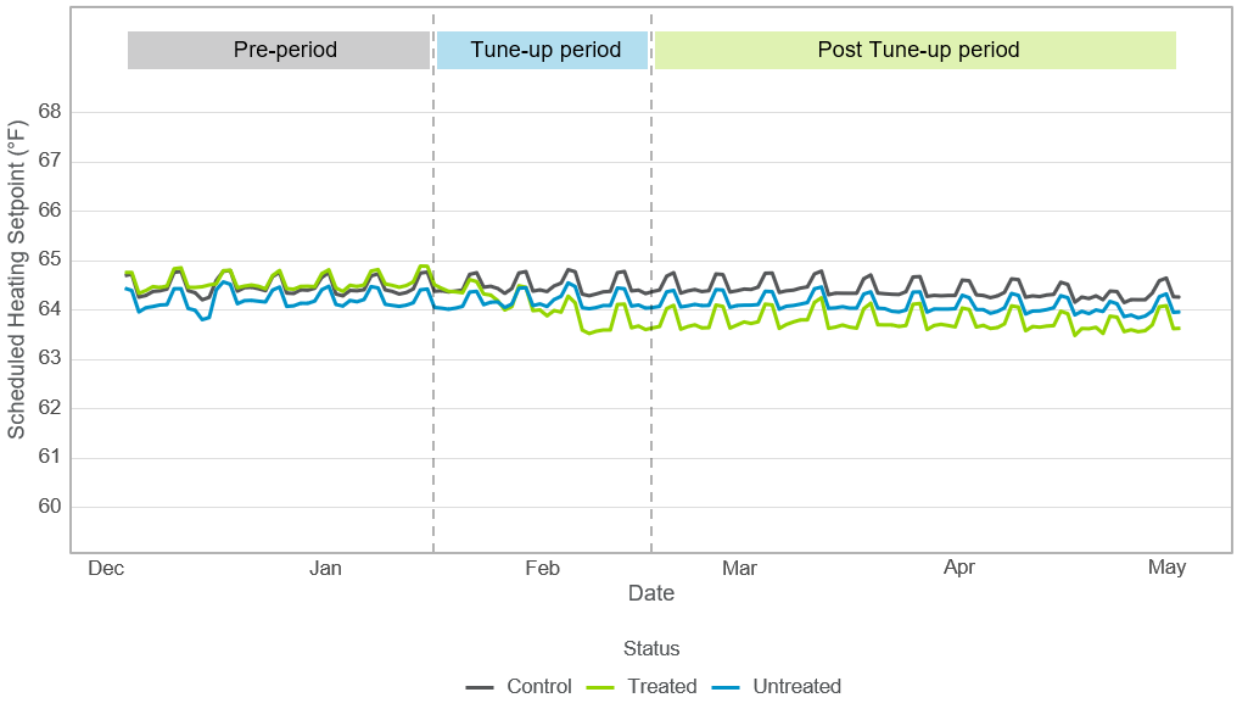
Source: Navigant analysis of Nest thermostat telemetry data

Figure A-5. Daily Scheduled Setpoints – Oil – Eversource



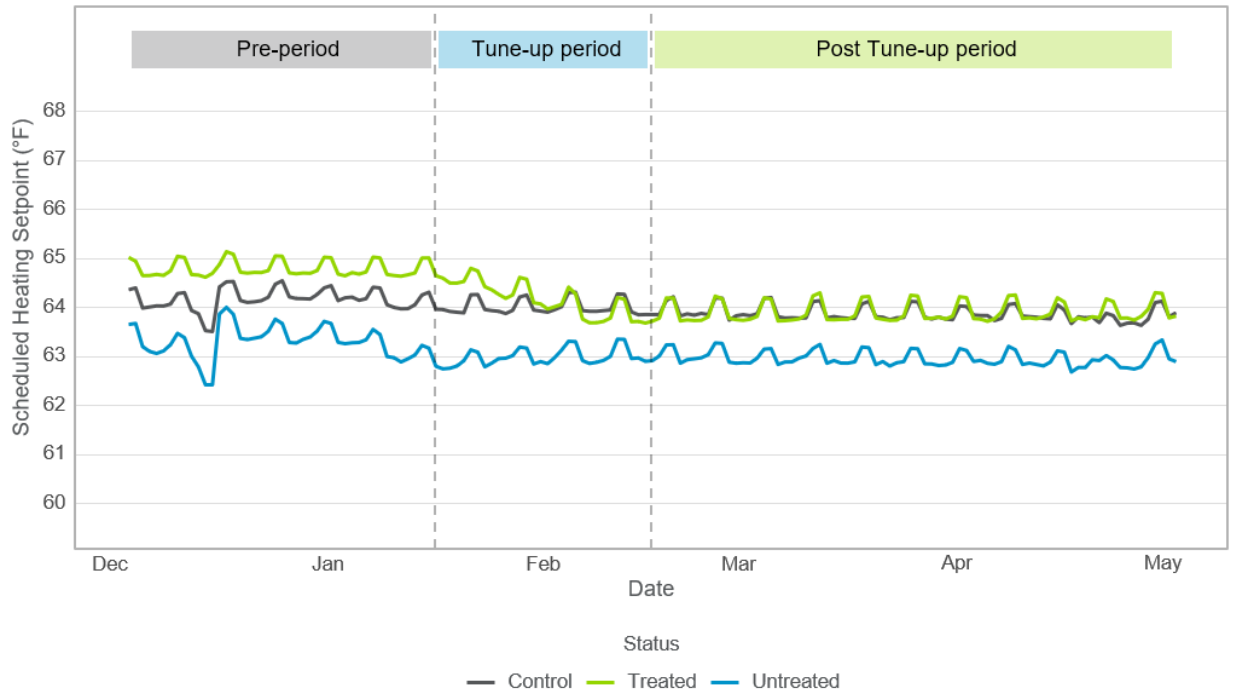
Source: Navigant analysis of Nest thermostat telemetry data

Figure A-6. Daily Scheduled Setpoints – Oil – All



Source: Navigant analysis of Nest thermostat telemetry data

Figure A-7. Daily Scheduled Setpoints – Propane – All



Source: Navigant analysis of Nest thermostat telemetry data

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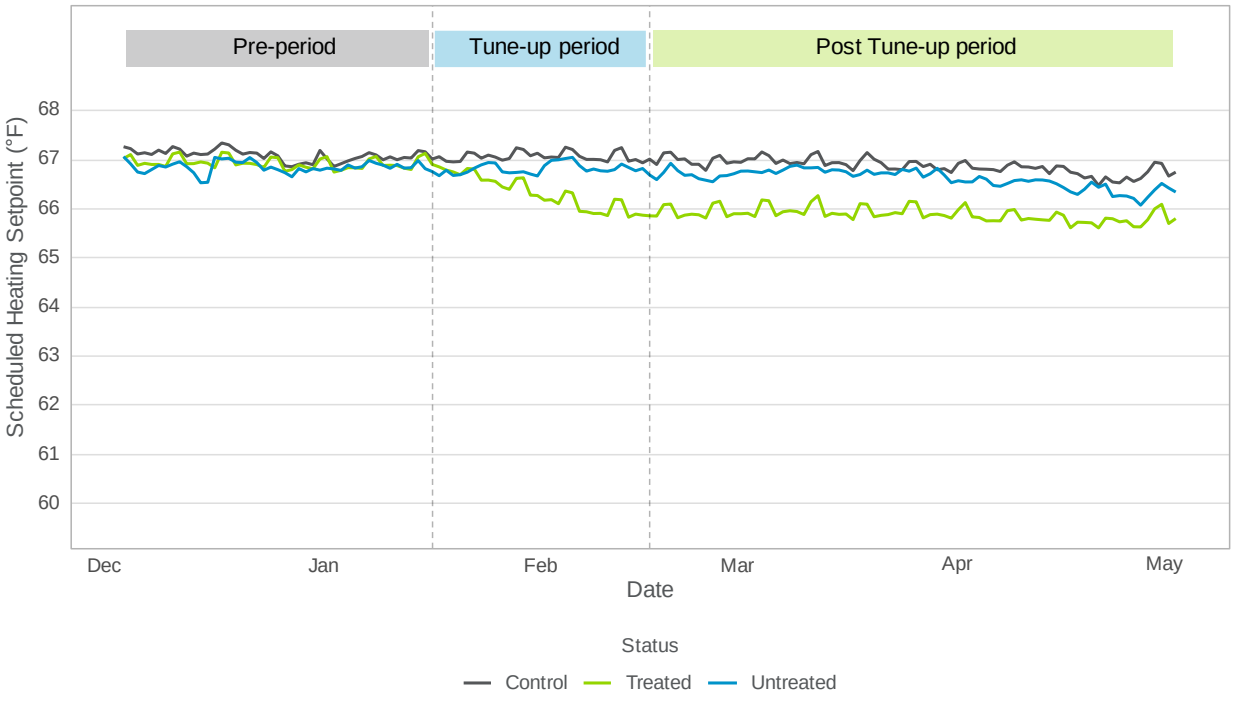
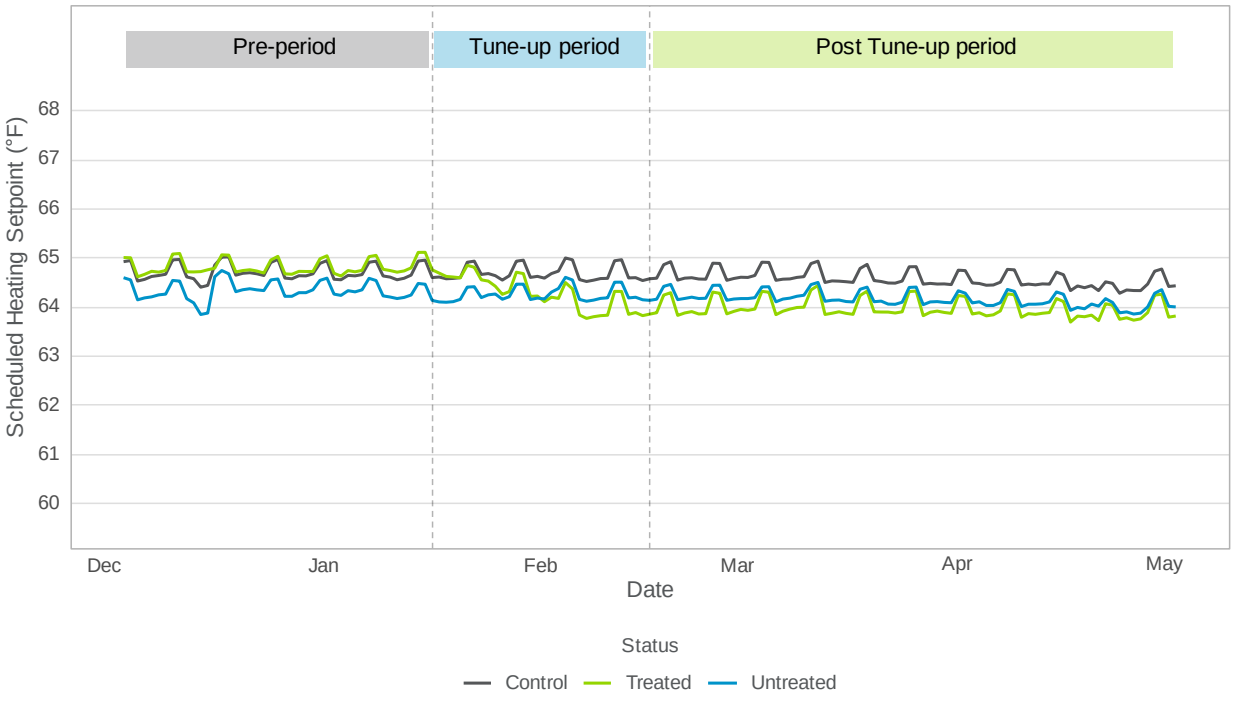
Figure A-8. Daily Scheduled Setpoints – Electric – All



Source: Navigant analysis of Nest thermostat telemetry data

Figure A-9. Daily Scheduled Setpoints – Non-Gas – All



Source: Navigant analysis of Nest thermostat telemetry data

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APPENDIX B. EXPLORATORY ANALYSIS – RUNTIME BY SUB-SEGMENT

B.1 Runtime Summary

Table B-1 shows a summary of runtime reduction for each sub-segment evaluated. This table presents runtime reduction in terms of both absolute reduction and percent reduction.

Overall, treated devices in the oil heating segment showed the lowest runtime reduction percentage at 3.28%. Treated devices in the electric heating segment showed the highest runtime reduction percentage at 7.90%.

Table B-1. Summary of Runtime Reduction for All Sub-Segments

Evaluation Segment	Treated Devices	Pre-RT (minutes)	RT Reduction (minutes)	% RT Reduction
All	**52,238**	**259.5**	**-10.9**	**-4.21%**
Gas-All	**34,480**	**259.0**	**-11.2**	**-4.31%**
Gas-NGrid	22,813	265.6	-12.2	-4.58%
Gas-EVS	11,667	246.1	-9.4	-3.80%
Non-Gas-All	**17,758**	**260.5**	**-10.6**	**-4.06%**
Oil-All	13,238	268.8	-8.8	-3.28%
Oil-NGrid	6,735	268.1	-8.2	-3.16%
Oil-EVS	5,912	273.7	-8.1	-2.99%
Oil-CLC	591	228.3	-9.0	-3.93%
Propane-All	2,768	243.7	-11.2	-4.61%
Electric-All	1,752	224.0	-17.7	-7.90%

Source: Navigant analysis of Nest thermostat telemetry data

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B.2 Runtime Summary by PA and Fuel Type

Table B-2 through Table B-11 provide the average daily heating runtimes for the control, ITT, and treated and untreated subgroups for each sub-segment analyzed. The exploratory analysis compares the heating runtimes between the pre-period and post tune-up period for each group. The analysis found that the SS program made the intended adjustments to scheduled heating setpoints in each sub-segment analyzed. In each sub-segment, the reduction in average daily heating runtime of the treated group is greater than the reduction observed in the control group.

Table B-2 and Table B-3 show the runtime reductions for the Gas segment by PA. National Grid devices had a slightly larger reduction in runtime (12.16 minutes) relative to Eversource devices (9.36 minutes).

Table B-2. Summary of Exploratory Runtime Analysis – Gas – National Grid

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.22	40.34	6.11	-
Average Daily Heating Runtime (min)	Control	253.19	179.78	-73.42	-
	Intent-to-Treat	256.31	176.73	-79.58	-6.16
	Treated	265.62	180.04	-85.58	-12.16
	Untreated	244.89	172.66	-72.27	1.15

Source: Navigant analysis of Nest thermostat telemetry data

Table B-3. Summary of Exploratory Runtime Analysis – Gas – Eversource

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.78	40.05	6.26	-
Average Daily Heating Runtime (min)	Control	241.08	170.92	-70.16	-
	Intent-to-Treat	242.89	166.98	-75.91	-5.75
	Treated	246.13	166.61	-79.52	-9.36
	Untreated	238.25	167.50	-70.76	-0.60

Source: Navigant analysis of Nest thermostat telemetry data

Overall, treated devices in the natural gas heating segment reduced their runtime by 11.17 minutes on average in the post tune-up period relative to control, as shown in Table B-4.

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Table B-4. Summary of Exploratory Runtime Analysis – Gas – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.40	40.57	6.16	-
Average Daily Heating Runtime (min)	Control	249.26	176.90	-72.36	-
	Intent-to-Treat	251.96	173.58	-78.39	-6.03
	Treated	259.03	175.50	-83.53	-11.17
	Untreated	242.87	171.09	-71.78	0.58

Source: Navigant analysis of Nest thermostat telemetry data

As seen in Table B-5 through Table B-7, treated devices in the oil heating segment showed similar runtime reductions relative to control, all in the 8-minute range. Overall runtime across groups was lowest for Cape Light Compact devices, likely due to the seasonal nature of occupancy for homes in the Cape Light Compact service territory.

Table B-5.Summary of Exploratory Runtime Analysis – Oil – National Grid

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		32.92	39.43	6.50	-
Average Daily Heating Runtime (min)	Control	264.17	184.54	-79.62	-
	Intent-to-Treat	263.88	179.69	-84.19	-4.57
	Treated	268.10	180.01	-88.09	-8.47
	Untreated	258.04	179.25	-78.79	0.83

Source: Navigant analysis of Nest thermostat telemetry data

Table B-6.Summary of Exploratory Runtime Analysis – Oil – Eversource

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.18	40.64	6.46	-
Average Daily Heating Runtime (min)	Control	269.49	186.19	-83.31	-
	Intent-to-Treat	269.49	182.19	-87.30	-3.99
	Treated	273.68	182.18	-91.50	-8.19
	Untreated	263.09	182.21	-80.89	2.42

Source: Navigant analysis of Nest thermostat telemetry data

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Table B-7.Summary of Exploratory Runtime Analysis – Oil – Cape Light Compact

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		35.84	40.05	4.21	-
Average Daily Heating Runtime (min)	Control	218.69	152.40	-66.30	-
	Intent-to-Treat	205.32	143.88	-61.44	4.86
	Treated	228.26	152.98	-75.28	-8.98
	Untreated	192.61	138.81	-53.80	12.50

Source: Navigant analysis of Nest thermostat telemetry data

Overall, treated devices in the oil heating segment reduced their runtime by 8.83 minutes on average in the post tune-up period relative to control, as shown in Table B-8.

Table B-8. Summary of Exploratory Runtime Analysis – Oil – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		33.67	39.99	6.32	-
Average Daily Heating Runtime (min)	Control	263.14	182.95	-80.19	-
	Intent-to-Treat	262.04	178.21	-83.83	-3.64
	Treated	268.81	179.79	-89.02	-8.83
	Untreated	252.90	176.07	-76.83	3.36

Source: Navigant analysis of Nest thermostat telemetry data

As shown in Table B-9, treated devices in the propane heating segment reduced their runtime by an average 11.23 minutes in the post tune-up period relative to control devices.

Table B-9. Summary of Exploratory Runtime Analysis – Propane – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		34.12	39.88	5.76	-
Average Daily Heating Runtime (min)	Control	230.67	161.51	-69.17	-
	Intent-to-Treat	227.54	156.66	-70.88	-1.71
	Treated	243.73	163.34	-80.39	-11.23
	Untreated	212.88	150.58	-62.30	6.87

Source: Navigant analysis of Nest thermostat telemetry data

Treated devices in the electric heating segment reduced their runtime by the largest amount relative to control among fuel types in the study, shown in Table B-10. These devices showed a 17.69 minute

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reduction in average runtime. Devices with electric heating also had the lowest average runtime across the season compared to other fuel types.

Table B-10. Summary of Exploratory Runtime Analysis – Electric – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		35.45	41.48	6.04	-
Average Daily Heating Runtime (min)	Control	213.80	149.64	-64.16	-
	Intent-to-Treat	207.35	136.01	-71.34	-7.19
	Treated	224.03	142.18	-81.85	-17.69
	Untreated	192.68	130.57	-62.12	2.04

Source: Navigant analysis of Nest thermostat telemetry data

Overall, treated devices in the non-gas heating segment reduced their average runtime by 10.57 minutes in the post tune-up period relative to control, shown in Table B-11. This was a smaller reduction than devices in the gas heating segment (11.17 minute reduction).

Table B-11. Summary of Exploratory Runtime Analysis – Non-Gas – All PAs

	Group	Pre-Period	Post Tune-Up	Δ	SS Impact
Period Dates		Dec 1 – Jan 13	Feb 14 – Apr 30	-	-
Average Daily Outdoor Temp (°F)		33.95	40.14	6.19	-
Average Daily Heating Runtime (min)	Control	251.72	175.34	-76.38	-
	Intent-to-Treat	249.64	169.57	-80.07	-3.69
	Treated	260.52	173.56	-86.96	-10.57
	Untreated	236.63	164.77	-71.86	4.52

Source: Navigant analysis of Nest thermostat telemetry data

B.3 Runtime Summary Graphics

Figure B-1 through Figure B-9 show average daily heating runtimes across all days for the ITT subgroups (treated and untreated) and the control group for each sub-segment analyzed. In the pre-period, the figures show that the treated groups typically have average runtimes that are higher than or approximately equal to the control groups. During the post tune-up period, the untreated and control groups maintain average heating runtimes that follow the trend of heating degree hours, having experienced no SS tune-up. In contrast, the trend in treated group runtimes shift down slightly from the trend observed in the pre-tune-up values.

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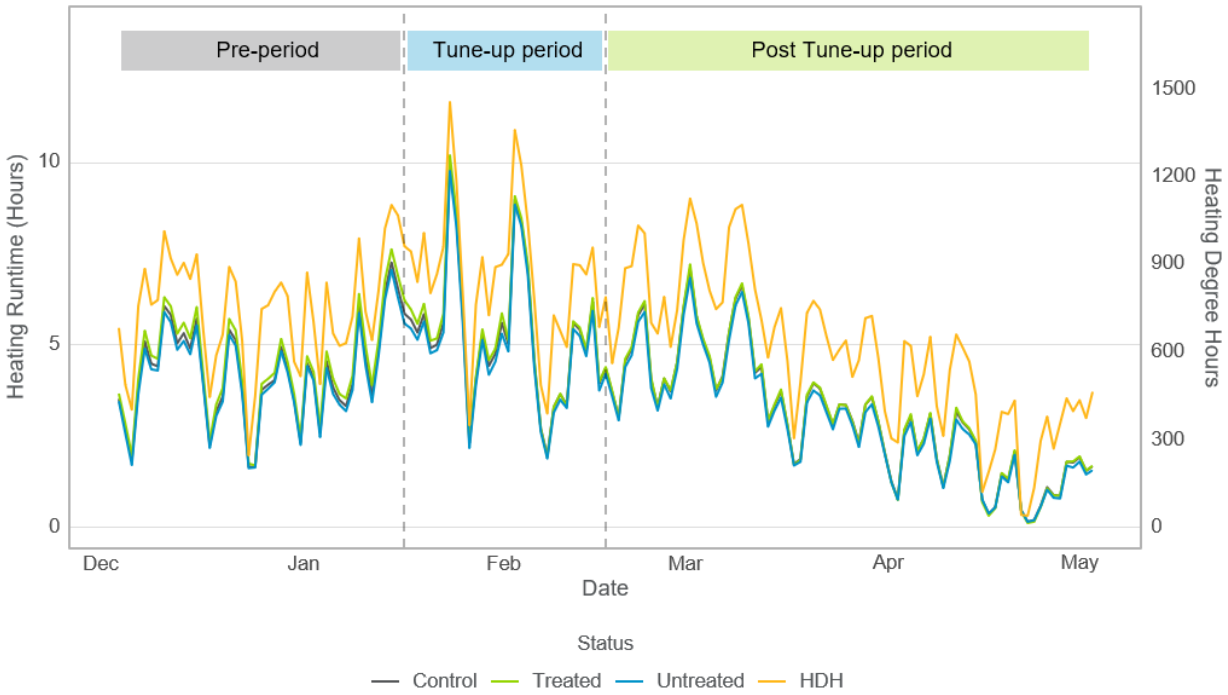
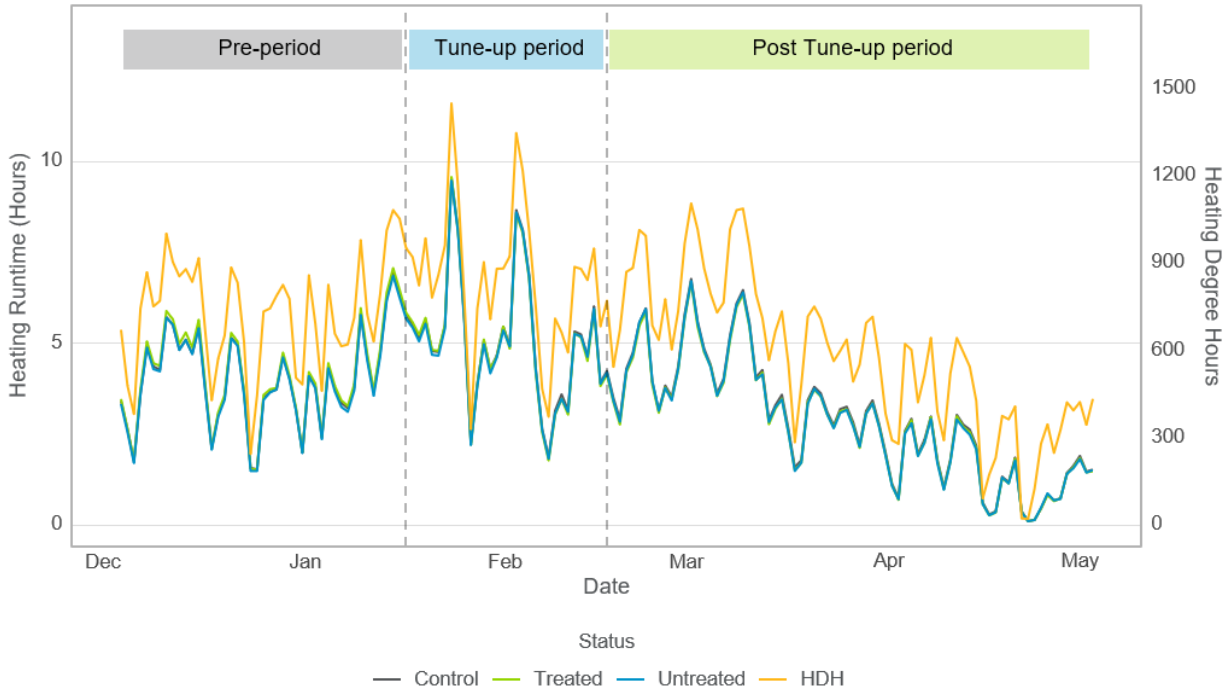
Figure B-1. Daily Heating Runtime – Gas – National Grid



Source: Navigant analysis of Nest thermostat telemetry data

Figure B-2. Daily Heating Runtime – Gas – Eversource



Source: Navigant analysis of Nest thermostat telemetry data

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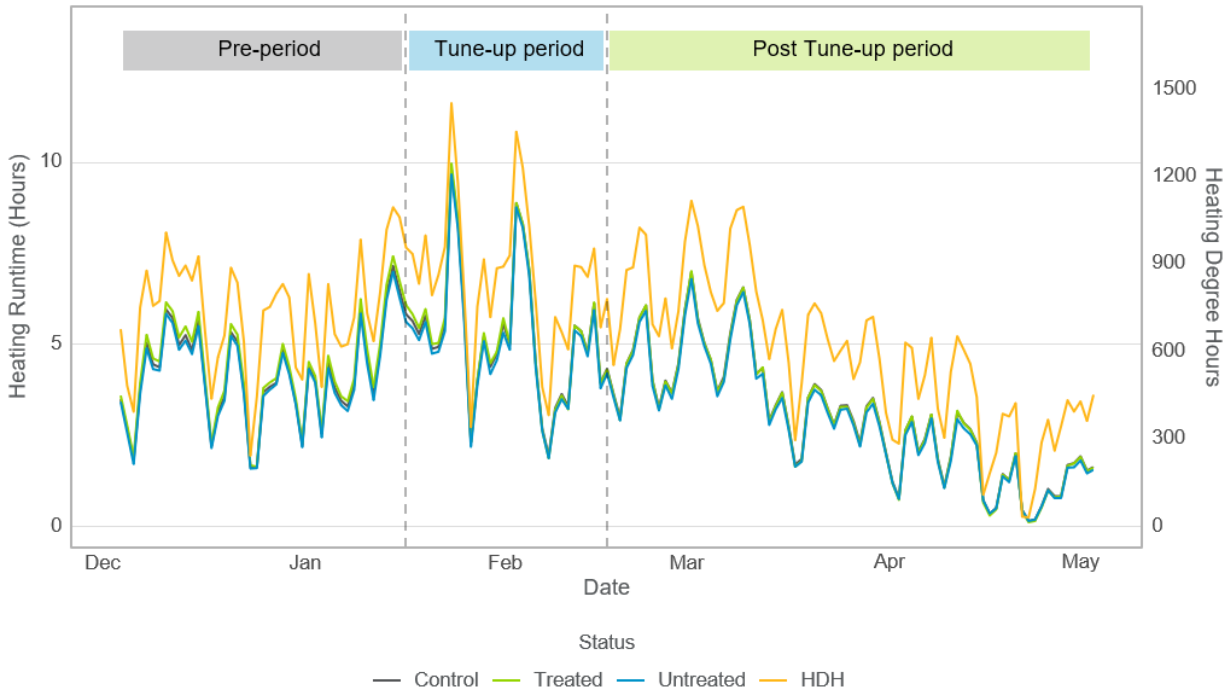
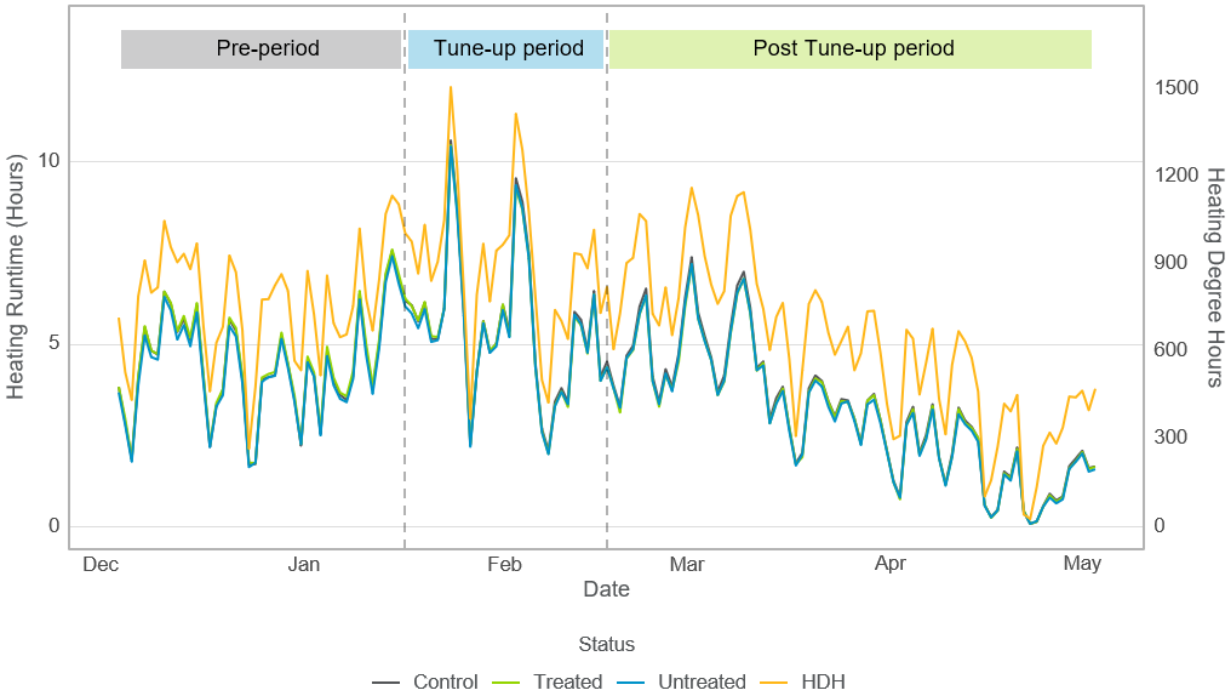
Figure B-3. Daily Heating Runtime – Gas – All



Source: Navigant analysis of Nest thermostat telemetry data

Figure B-4. Daily Heating Runtime – Oil – National Grid



Source: Navigant analysis of Nest thermostat telemetry data

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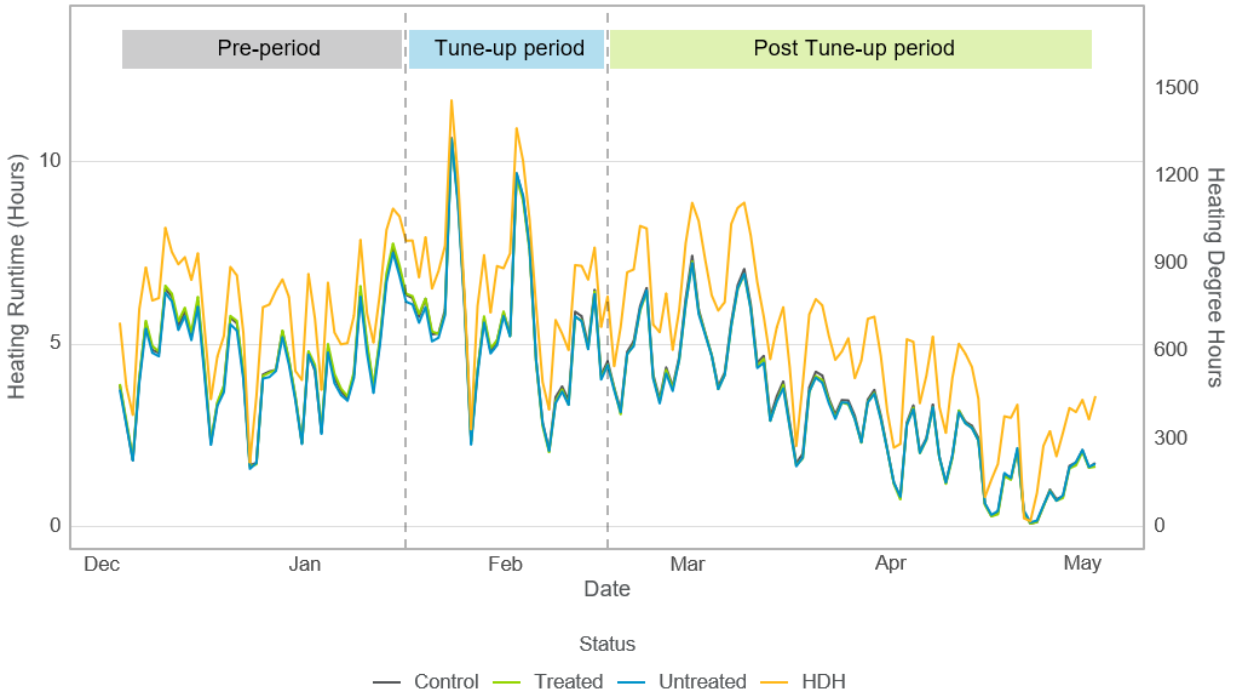
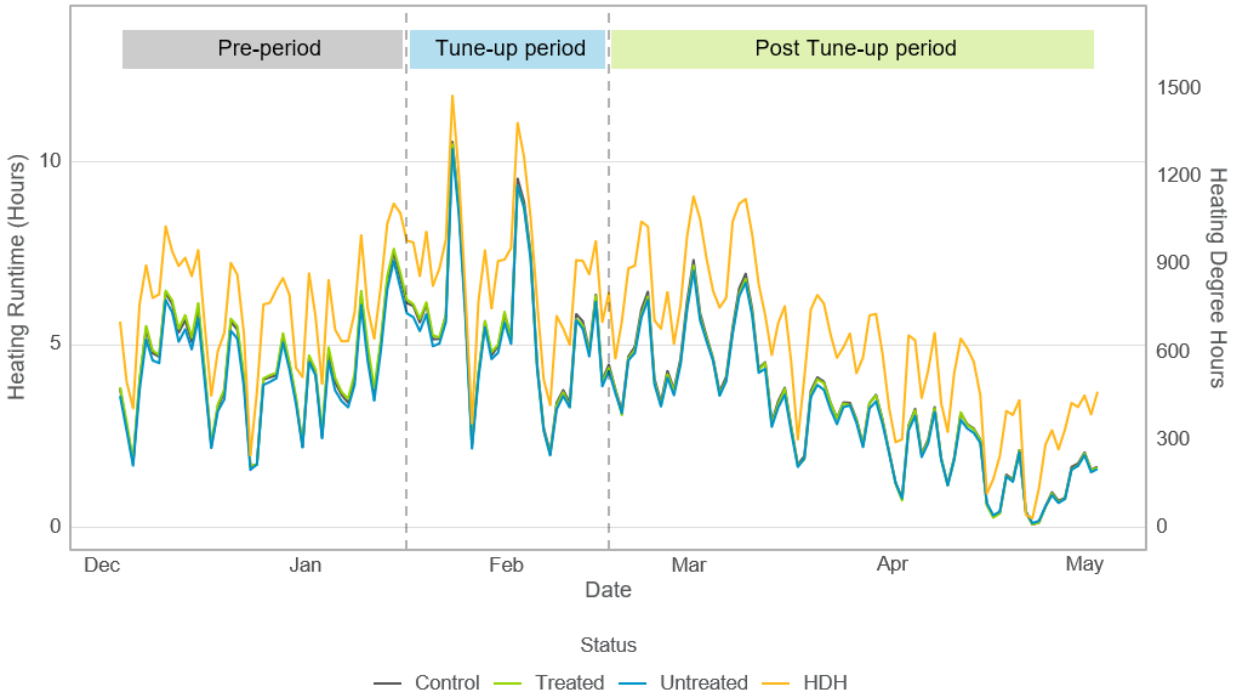
Figure B-5. Daily Heating Runtime – Oil – Eversource



Source: Navigant analysis of Nest thermostat telemetry data

Figure B-6. Daily Heating Runtime – Oil – All



Source: Navigant analysis of Nest thermostat telemetry data

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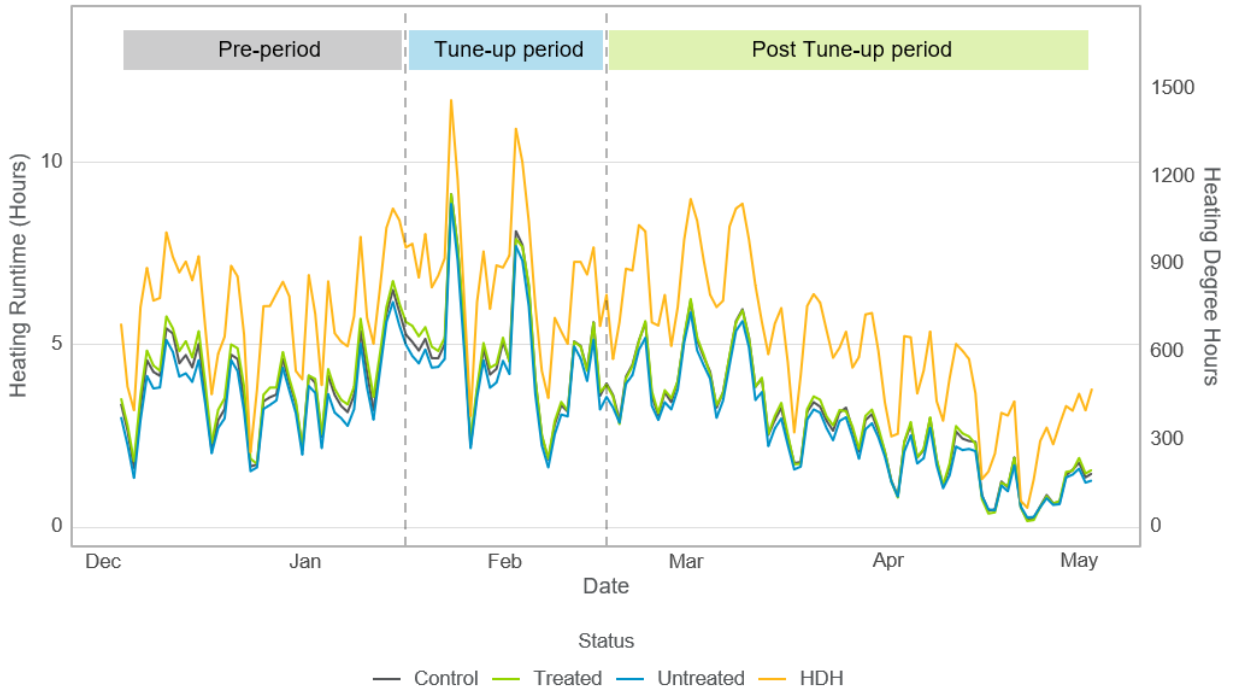
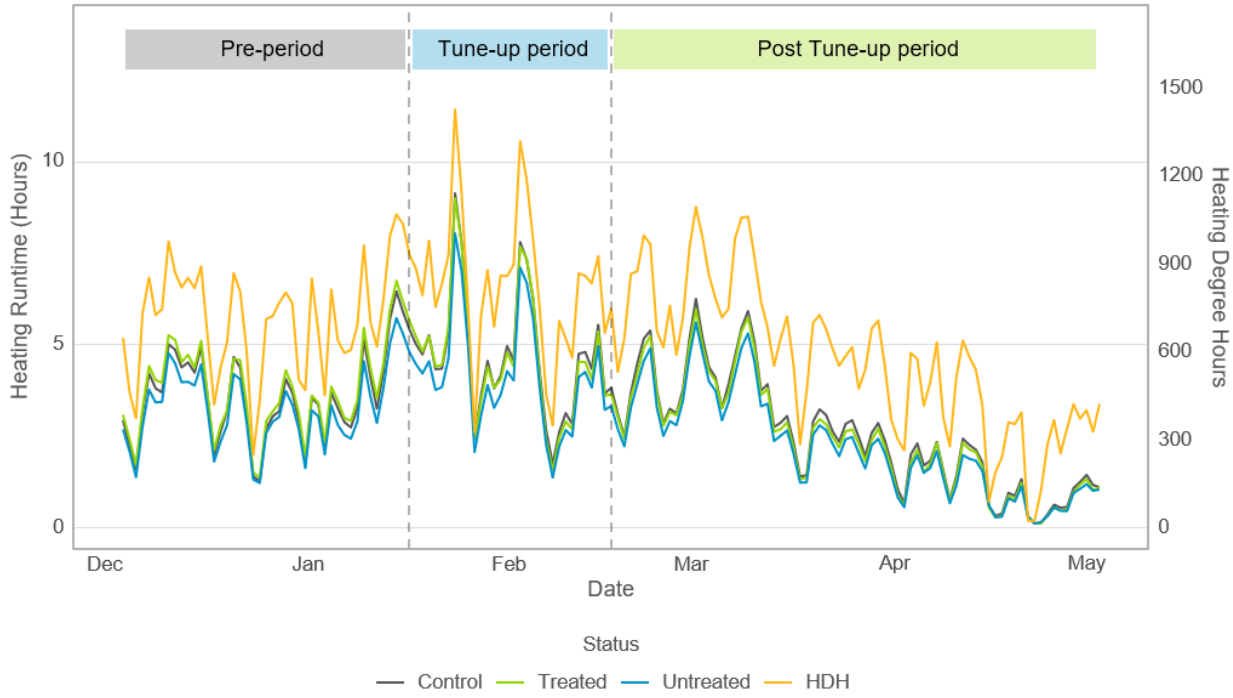
Figure B-7. Daily Heating Runtime – Propane – All



Source: Navigant analysis of Nest thermostat telemetry data

Figure B-8. Daily Heating Runtime – Electric – All



Source: Navigant analysis of Nest thermostat telemetry data

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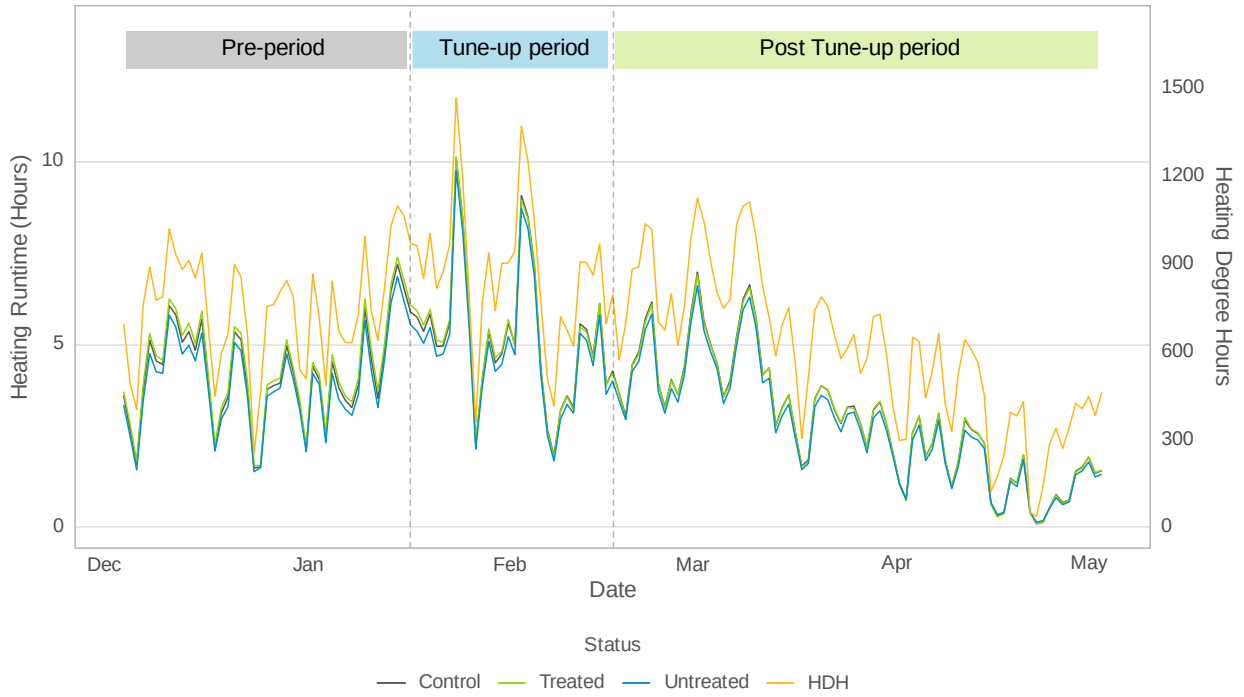
Figure B-9. Daily Heating Runtime – Non-Gas – All



Source: Navigant analysis of Nest thermostat telemetry data

APPENDIX C. EXPLORATORY ANALYSIS – PREVIOUS SS PARTICIPATION

Table C-1 shows Google assigned 8,953 devices that opted in for 2014-15 winter SS to the 2018-19 winter SS ITT group. 5,663 of these devices opted in again, for an opt-in rate of 63.3%.

Table C-1. Summary of Previous Winter SS Participation

2014-15 Winter SS Status	2018-19 Winter SS Status			Total
	Control	Intent-to-Treat		
		Treated	Untreated	
Opt in*	3,881 *3%*	5,663 *4%*	3,290 *2%*	**12,834** ***9%***
No thermostat installed / Did not opt in / Did not qualify	37,999 *27%*	46,575 *33%*	42,218 *30%*	**126,792** ***91%***
Total	**41,880** ***30%***	**52,238** ***37%***	**45,508** ***33%***	**139,626**

Source: Navigant analysis of Nest thermostat enrollment data

Table C-2 shows Google assigned 8,948 devices that opted in for a prior summer SS to the 2018-19 winter SS ITT group. 5,468 of these devices opted in again, for an opt-in rate of 61.1%.

Table C-2. Summary of Previous Summer SS Participation

Prior Summer SS Status	2018-19 Winter SS Status			Total
	Control	Intent-to-Treat		
		Treated	Untreated	
Opt in*	3,796 *3%*	5,468 *4%*	3,480 *2%*	**12,744** ***9%***
Not offered / No thermostat installed / Did not opt in / Did not qualify	38,084 *27%*	46,770 *34%*	42,028 *30%*	**126,882** ***91%***
Total	**41,880** ***30%***	**52,238** ***37%***	**45,508** ***33%***	**139,626**

Source: Navigant analysis of Nest thermostat enrollment data

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Table C-3 shows a comparison of devices with and without prior SS participation by season. Treated devices with prior winter participation showed a setpoint reduction larger than the average across all treated devices (0.73°F) at 0.86°F.

Table C-3. Prior SS Participation Setpoint Comparison

	Prior Summer Comparison		Prior Winter Comparison	
	No Prior Summer Participation	Prior Summer Participation	No Prior Winter Participation	Prior Winter Participation
Treated Devices	46,770	5,468	46,770	5,663
Pre-SP	65.3	65.8	65.4	65.0
SP Reduction	-0.73°F	-0.74°F	-0.72°F	-0.86°F
% SP Reduction	-1.12%	-1.12%	-1.10%	-1.33%

Source: Navigant analysis of Nest thermostat telemetry data

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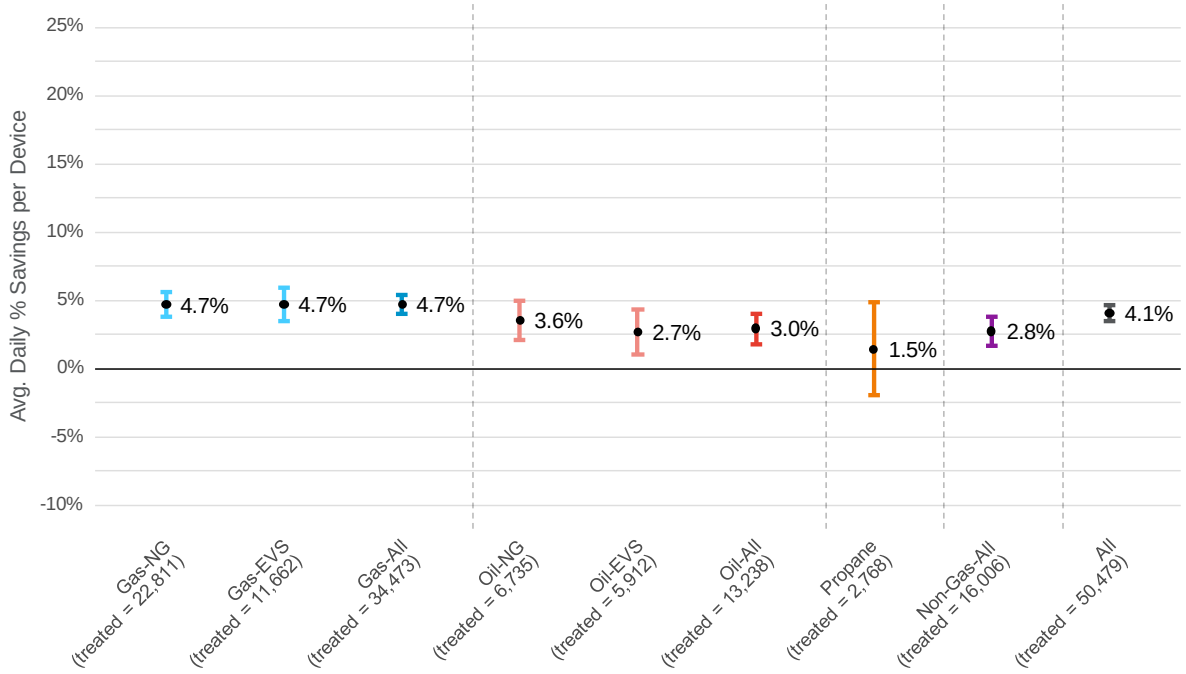
APPENDIX D. IMPACT ANALYSIS – IMPACTS BY SUB-SEGMENT

Figure D-1 shows the average daily percent savings per device (in therms) for each PA and Fuel Type sub-segment analyzed.

Gas segments had the highest percent savings at 4.7%. The propane segment had the lowest percent savings at 1.5%, and the result was not statistically different from zero. The propane segment had a comparatively small sample size at 2,768 treated devices, which may have contributed to the statistically insignificant estimate.

Figure D-1. Percent Savings (Therms) by Evaluation Segment



Source: Navigant analysis

Figure D-2 shows the average daily percent savings per device (in kWh) for each PA and Fuel Type sub-segment analyzed.

The electric segment had the highest percent savings at 9.6%, though the 90% confidence bounds on the estimate were wide, ranging from 3.2% to 16%. The electric segment had the smallest sample size at 1,752 treated devices, which may have contributed to the wide confidence interval.

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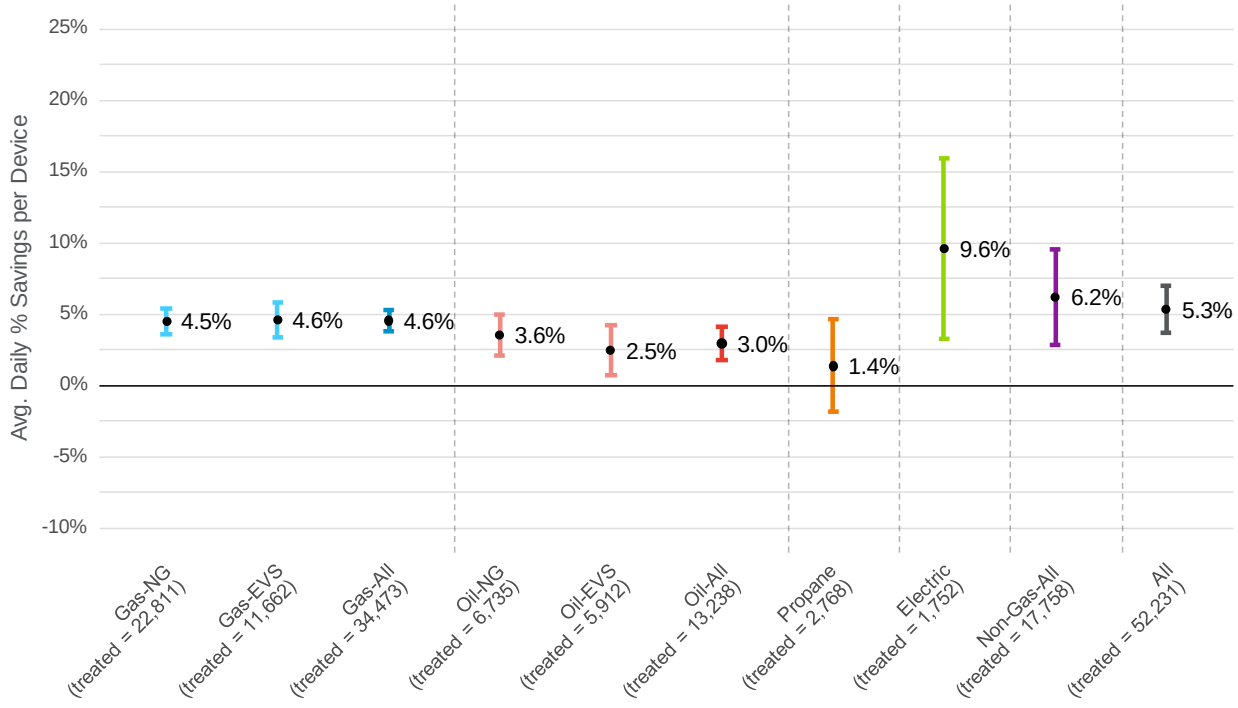
Figure D-2. Percent Savings (kWh) by Evaluation Segment



Source: Navigant analysis

Figure D-3 shows the average daily percent savings per device (in MMBtu) for each PA and Fuel Type sub-segment analyzed.

These combined savings are largely driven by therms savings, with the exception of the Electric segment.

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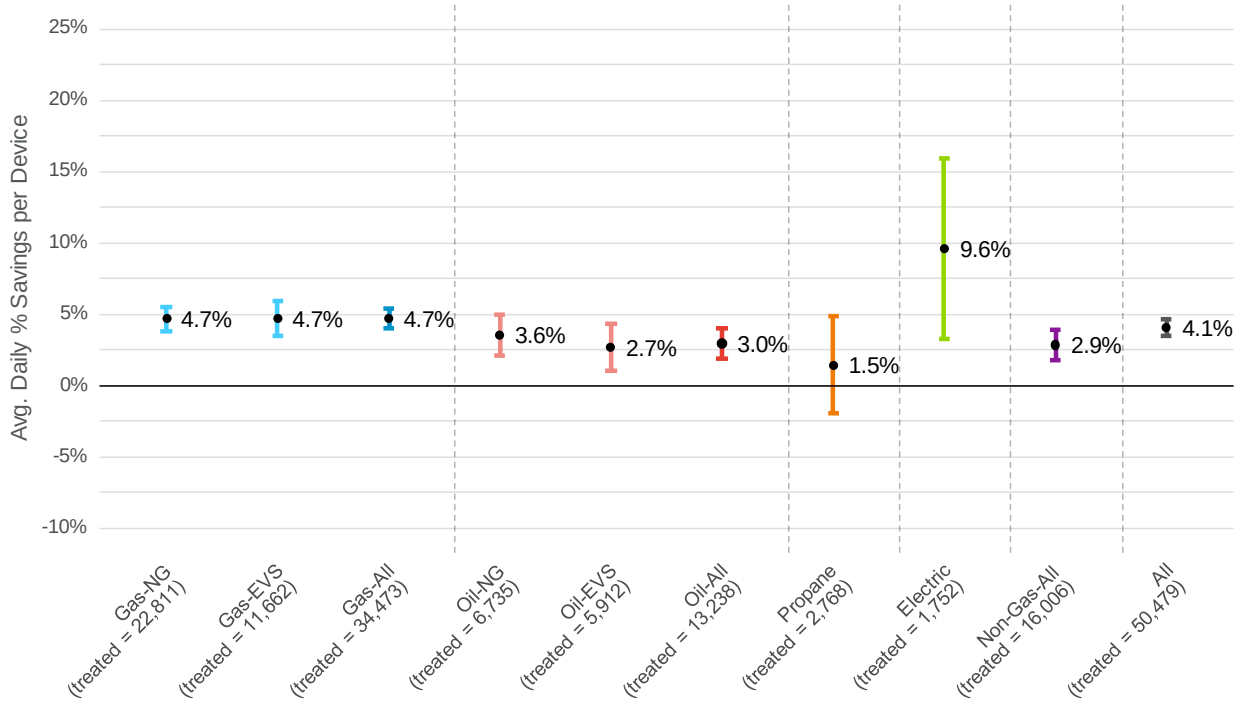
Figure D-3. Percent Savings (MMBtu) by Evaluation Segment



Source: Navigant analysis

Table D-1 presents the baseline usage, savings, and average percent savings (in therms and kWh) for each PA and Fuel Type sub-segment analyzed.

Table D-1. Savings per Day by Evaluation Segment†

Primary Heating Fuel	PA	Program Period - Therms			Program Period - kWh		
		Baseline Usage per Day	Savings per Day	Percent Savings	Baseline Usage per Day	Savings per Day	Percent Savings
Natural Gas	National Grid	3.25	0.15	4.69%	1.56	0.07	4.53%
Natural Gas	Eversource	3.00	0.14	4.73%	1.51	0.07	4.62%
Natural Gas	***All***	3.17	0.15	4.71%	1.54	0.07	4.56%
Oil	National Grid	3.42	0.12	3.55%	1.40	0.05	3.57%
Oil	Eversource	3.44	0.09	2.71%	1.41	0.03	2.49%
Oil	***All***	3.39	0.10	2.95%	1.39	0.04	2.95%
Propane	***All***	2.69	0.04	1.46%	1.48	0.02	1.38%
Electric	***All***	N/A	N/A	N/A	14.29	1.37	9.60%
Non-Gas	***All***	3.27	0.09	2.76%	2.66	0.17	6.22%
All	**All**	3.20	0.13	4.07%	1.92	0.10	5.32%

† Navigant modeled each segment separately; results are not additive.

Source: Navigant analysis

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Table D-2 presents the savings per treated thermostat and total fuel savings (in therms and kWh) for each PA and Fuel Type sub-segment analyzed.

The majority of fuel savings came from Natural Gas segment, which also had the highest number of treated thermostats at 34,480. The Natural Gas segment also had the highest total electric savings at 252 MWh. The Electric segment had the second highest at 246 MWh despite having the fewest number of treated thermostats at 1,752.

Table D-2. Savings per Treated Thermostat by Evaluation Segment†

Primary Heating Fuel	PA	Number of Treated Thermostats	*Program Period - Therms*		*Program Period - kWh*	
			Savings per Treated Thermostat	Total Fuel Savings	Savings per Treated Thermostat	Total Electric Savings
Natural Gas	National Grid	22,813	15.91	363,000	7.34	168,000
Natural Gas	Eversource	11,667	14.77	172,000	7.26	84,700
Natural Gas	***All***	***34,480***	15.54	536,000	7.32	252,000
Oil	National Grid	6,735	12.70	85,500	5.24	35,300
Oil	Eversource	5,912	9.77	57,800	3.67	21,700
Oil	***All***	***13,238***	10.50	139,000	4.30	56,900
Propane	***All***	***2,768***	4.11	11,400	2.14	5,920
Electric	***All***	***1,752***	N/A	N/A	141	246,000
Non-Gas	***All***	***17,758***	9.45	151,000	17.3	307,000
All	**All**	**50,486**	13.59	686,000	10.66	557,000

† Navigant modeled each segment separately; results are not additive.

Source: Navigant analysis

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APPENDIX E. RANDOMIZATION VERIFICATION

Table E-1 provides a summary of the percent difference in mean heating runtime for the ITT and control groups for each sub-segment analyzed.

Natural Gas – National Grid and Natural Gas – All had statistically significant differences in pre-period runtime between the ITT and control groups. These differences were less than 1.5% and were controlled for by including pre-period data for ITT and control in the fixed effects model.

Table E-1. Verification of Randomization by PA and Fuel Type

Primary Heating Fuel	PA	*Mean Heating Runtime (Hours)*		Percent Difference	P-value
		ITT	Control		
Natural Gas	National Grid	185	183	-1.26%	0.058*
Natural Gas	Eversource	175	174	-0.70%	0.487
Natural Gas	***All***	182	180	-1.09%	0.050*
Oil	National Grid	191	191	0.12%	0.911
Oil	Eversource	195	194	-0.36%	0.769
Oil	***All***	190	190	0.29%	0.719
Propane	***All***	164	167	1.33%	0.479
Electric	***All***	149	152	2.03%	0.512
All	**All**	181	180	-0.50%	0.263

Source: Navigant analysis of Nest thermostat telemetry data

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