THE CADMUS GROUP, INC.

Final Report

Wi-Fi Programmable Controllable Thermostat Pilot Program Evaluation

Part of the Massachusetts 2011 Residential Retrofit and Low Income Program Area Evaluation

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1. Executive Summary

This report presents the impact and process evaluation of the 2011 Wi-Fi Programmable Controllable Thermostat Pilot Program conducted by The Cadmus Group, Inc. (Cadmus). The findings, conclusions, and recommendations have been drawn from data collection activities that included billing analyses, site visits, and interviews with program administrator (PA) staff, contractors, and participating customers. Key findings of this evaluation include:

- **The gas savings for single thermostat installations (11% per thermostat) are considerably larger than for two thermostat installations (8% per thermostat)**. The multiple thermostats likely are controlling the same heating system but in a different lower usage zone or possibly serving a secondary heating system.
    - ➢ **Recommendation:** If a full scale Wi-Fi thermostat program is rolled out, consider these saving differentials during the program design and planning process.

- **The gas savings for non-programmable thermostat replacements (10% per thermostat) are larger than for programmable thermostat replacements (8% per thermostat**). As expected when the Wi-Fi thermostats are replacing programmable thermostats, the percent savings are lower than for non-programmable thermostats. The Wi-Fi savings for programmable thermostat replacements form the lower bound of the heating season savings expected from the Wi-Fi thermostat installations.
    - ➢ **Recommendation:** If a full scale Wi-Fi thermostat program is rolled out, use separate percent savings estimates for heating with non-programmable and for heating with programmable thermostats.

- **The electric savings for non-programmable thermostat replacements are effectively equal to those for programmable thermostat replacements.** Not all occupants use the full functionality of their programmable thermostats. In cases where an occupant has a programmable thermostat but declines to use the schedule and set point functionality the thermostat is effectively a non-programmable thermostat.
    - ➢ **Recommendation:** If a full scale Wi-Fi thermostat program is rolled out, record the baseline set points and schedule as well as recording whether the baseline thermostat was programmable or non-programmable. Use this information to assess whether the baseline thermostat behavior was equivalent to a programmable thermostat or not.

- **Electric savings associated with Wi-Fi enabled thermostats vary significantly from one house to another**. The savings are very dependent on occupant behavior and baseline set point information. This baseline set point information was based on participant recollections of prior set points, which may be incorrect. To improve evaluability and increase confidence in savings, pre- and post-metered data are preferred.
    - ➢ **Recommendation:** Install energy metering equipment on air conditioner and air handler units belonging to program participants covering a period including pre-installation and post-installation time periods. Use this information to estimate program savings. This would increase confidence in the program savings estimate by showing how much energy is consumed for cooling prior to thermostat installation.

The exact savings for each site could be calculated without making baseline assumptions or relying on participants to remember prior set points and schedules.

- **For some participants the energy savings benefits of a Wi-Fi enabled thermostat are similar to those of a standard programmable thermostat.** Whether a participant saves more energy with a Wi-Fi thermostat than they would with a programmable thermostat is difficult to quantitatively predict as the savings are reliant on participant behavior.
  - **Recommendation:** Determine the portion of participants that are using the programmable functionality of their thermostats when the Wi-Fi thermostats were installed. When a participant installs a Wi-Fi thermostat, continue to gather information about the baseline system including thermostat type and program status for future program evaluation purposes.
- **Participant training process.** Although there was general satisfaction among participants regarding training, a few suggested a more intensive training session.
  - **Recommendation:** The installer should ask if the participant would like the installer to spend more time explaining technical aspects of thermostats at installation and/or to provide step-by-step instructions on how to use the Web portal. The participant would then have a chance to get more in-depth training if desired.
  - **Recommendation:** For participants who require more assistance operating the Wi-Fi thermostat, online tutorials or videos should be made available. Links to these tutorials on the Web portal could be distributed at installation.
- **Web portal.** Survey respondents were asked about potential improvements to the Web portal. Most respondents used the Website and reported that it was easy to use. Several participants recommended improvements.
  - **Recommendation:** The Web portal interface should be more user-friendly and this may be facilitated by improving the visibility of button functions and thereby lessening confusion when navigating the Website. The Web portal's help tutorial should also have a highly visible link to a FAQ page to answer common questions. The Web portal should be easier to use by households with two thermostats so each thermostat's activity is distinguishable.
- **Program processes.** In general, participants expressed satisfaction with the Wi-Fi pilot program processes. Only a few participants made suggestions for program improvements.
  - **Recommendation:** A few participants noted that most of their acquaintances who are also National Grid customers were not aware of the Wi-Fi thermostat pilot program. National Grid should provide more marketing materials, such as press releases or bill inserts, to increase awareness of the program.

2. Introduction

Overview of the Wi-Fi Thermostat Pilot Program

The Wi-Fi Programmable Controllable Thermostat Pilot Program, designed and implemented by National Grid, offers customers a free Wi-Fi thermostat that can be programmed and controlled remotely. The Ecobee Wi-Fi thermostat used in this pilot program has several unique features many of which help customers save energy. The thermostat:

- Allows remote access to the unit and control of the heating and cooling (HVAC) system from a Web portal or smartphone application.
- Offers the option to program a custom schedule to reduce energy use when the user is away from the home.
- Reports on performance of the HVAC system.
- Alerts users when a problem arises with their HVAC system or when it is time for equipment maintenance.
- Displays the current weather and five-day forecast.

The goal of the pilot program is to assess the gas and electric savings associated with Wi-Fi thermostats and the feasibility of implementing a full scale program. Eligible participants must own a home heated by a natural gas furnace and must use a wireless internet router. It is preferred that customers have an AC unit that is controlled by the same thermostat as their furnace, but this is not a requirement.

Gem Plumbing and Heating (Gem), a subcontractor to National Grid, installed the Wi-Fi thermostats in participants' homes. During the installation process, the installer presented a short overview to the participant about the thermostat unit and how to set schedules and set points. The installer also programmed the schedules and set points at the participant's request. A total of 86 households participated in the program accounting for 123 thermostats. Sixty-nine households were located in Massachusetts and 17 households were located in Rhode Island.

Evaluation Objectives

Cadmus conducted both an impact and a process evaluation of the Wi-Fi Programmable Controllable Thermostat Pilot Program. The goal of the impact evaluation was to determine the level of gas savings attributable to the installation of the controllable thermostat and also assess electric savings for homes that used the same thermostat to control their AC unit. The primary objective of the process evaluation was to gain insight into the effectiveness of the program from participant, contractor, and program manager perspective and to inform recommendations for improving future program delivery. Our methodology and findings are described below.

3. Methodology

Impact Evaluation

The goal of the impact evaluation was to estimate the gas and electric savings attributable to the Ecobee Wi-Fi thermostat. To estimate gas savings, we conducted a billing analysis on 66 participant homes; to estimate electric savings we conducted analysis on site-specific data collected at 14 participant homes.

Estimating Gas Savings

National Grid provided Cadmus with monthly gas billing data from January 2009 through April 2012 for the Massachusetts and Rhode Island participants. To achieve the most accurate results, a billing analysis should include data for the 12 months immediately before and immediately following installation. For this analysis, complete billing data was available for almost all sites.

Cadmus obtained daily temperature weather data from the National Oceanic and Atmospheric Administration's National Climatic Data Center for the three weather stations, Providence – RI, Worcester – MA, and Concord – MA, which corresponded to the pilot participants' zip codes. From the daily weather data, we calculated the base 65 reference temperature heating degree days (HDDs).[1] We then matched the participant billing data to the nearest weather station by zip code and matched each monthly billing period to the associated base 65 HDDs.

In order to normalize for the different billing cycles and varying meter read dates, we allocated the gas usage (in therms) and the associated HDDs to calendar months. In our monthly allocation process, we first obtained the average daily usage and HDDs from the billing periods that spanned each month. Next, we multiplied the average daily usage and HDDs by their associated number of days in the calendar month to obtain the total usage and total HDDs for each calendar month.

Next, we applied the data screening and criteria shown in Table 1. If a participant failed any of these screens, we excluded that site's data from our billing analysis. We also excluded homes from our analysis that consumed less than an average of one therm per day in either the pre- or post-installation period, as this may indicate insufficient heating usage or that the participant home was vacant. Also, upon examining the summer base load months, we removed sites with substantial increases in usage since that could indicate there were additional occupants or that another water heater had been installed.

1 This is defined as the number of degrees below 65 Fahrenheit. For example, the base 65 HDD for a daily temperature of 50 degrees Fahrenheit is 15.

Table 1. Participant Screening for Gas Analysis

Site-Level Screening Criterion	Number of Participants Dropped
Fewer than six paired months in the pre or post period	8
Base load increase in summer months	8
Heating energy usage changed by more than 70% after implementation[2]	2
Heating energy averaged less than 1 therm per day either in pre- or post-installation period	1
Pool and spa usage patterns	1
Total Participants Screened Out	20
Total Participants Used in Analysis	66

Using these criteria, we screened out 20 of 86 participants, or 23%. Sixty-six participants had sufficient billing data for our analysis, and these sites are used in our regression modeling.

Table 2 lists the characteristics of the Ecobee Wi-Fi thermostat installation pilot participant homes. As shown in the table, the characteristics of the entire population of pilot participants are very similar to the group of 66 participants we selected as a sample for the billing analysis. Since separate models are estimated for participants installing a single thermostat and two thermostats, those averages are also presented.

Table 2. General Characteristics of Wi-Fi Thermostat Pilot Participants

Group	Number of Participant Homes	Number of Thermostats Installed	Average Home Area (sf)	Average Furnace Capacity (BTU per Home)	Average Furnace Age (Years)	Average Number of Thermostats Installed per Home
Population	86	123	2,267	104,210	10	1.43
Billing Analysis Group (1 Thermostat)	43	43	1,916	96,849	12	1.00
Billing Analysis Group (2 Thermostats)	23	46	2,706	111,630	8	2.00
Billing Analysis Group Overall	66	89	2,191	102,000	10	1.35
Billing Analysis Group (Non-Programmable Thermostats)	23	30	2,211	96,783	11	1.30
Billing Analysis Group (Programmable Thermostats)	43	59	2,180	104,791	10	1.37

[2] The extreme percent change screens are often applied in billing analysis to remove sites with unexpected percent changes. In this case, both of these large percent changes were due to prolonged vacancies and zero readings in either the pre or post periods. These sites were dropped from the final model group because they skewed the model savings by their inclusion and did not yield representative insights to what the thermostat savings were for the sites.

To determine gas savings, we used the fixed-effects modeling method shown below. This method pooled monthly time-series billing data, which corrected for differences between the pre- and post-installation period weather and in the usage magnitudes among participants. The fixed-effects model normalized this usage variation across the participants by using a separate intercept for each customer in the model estimation.

$$ADC_{it} = \alpha_i + \beta_1 AVGHDD_{it} + \beta_2 POST * AVGHDD_{it} + \beta_{3..13}.MONTH_t +_t \varepsilon_{it}$$

Where, for each participant 'i' and calendar month 't,'

ADC_{it}	=	average daily gas consumption during the pre- and post-installation periods.
α_i	=	average daily non-weather-sensitive base load for each participant that is part of that fixed-effects specification.
β_1	=	average daily gas usage per HDD in the pre-installation period.
$AVGHDD_{it}$	=	average daily base 65 HDDs based on home location.
β_2	=	gas heating savings per HDD as a result of thermostat installation(s).
$POST_t$	=	a dummy variable that is 0 in the pre-period and 1 in the post-period.
$POST_t$ $*AVGHDD_{it}$	=	an interaction of $POST_t$ and $AVGHDD_{it}$.
β_3 - β_{13}	=	incremental pre-period average daily usage for each billing month compared to December.
MONTH $_t$	=	an array of bill month dummy variables (Jan, Mar, …, Nov), 0 otherwise[3]
ε_{it}	=	the modeling estimation error.

The model directly estimates the thermostat savings (β_2). The inclusion of the interaction of the HDDs and the post-variable *($POST_t$)* allows for the possibility of obtaining weather-normalized savings by specifically isolating only the heating energy savings. For this billing analysis, Cadmus used the most recent 15 years of Typical Meteorological Year (TMY3) data (1991-2005) to calculate normalized HDDs and weather-normalized savings estimates.[4] Separate models were estimated for participants installing a single thermostat and two thermostats.

Estimating Electric Savings

Cadmus performed site visits at 14 homes where Wi-Fi thermostats controlled AC units. At three of the homes, two thermostats had been installed, bringing the total number of thermostats we

3 We excluded one of the dummy variables (December) from the independent variables to avoid the 12 monthly indicators forming perfect co-linearity with the intercepts. The remaining 11 individual intercepts include the seasonality from December.

4 This TMY3 series (1991-2005) is the latest available normal weather series. The 30-year TMY2 (1971-2000) series shows higher normal HDDs (6,468), but we deemed the TMY3 series to be more appropriate as it reflects the warming trend evident in more recent years.

observed to 17.[5] Site visits were performed in September 2011, after the Ecobee thermostat had been installed.

Data Collection

During site visits, Cadmus collected data on parameters such as equipment, occupant behavior, and environmental conditions. For the equipment data collection, we performed a spot measurement of the true power of both the outdoor AC unit and the fan. We also recorded information from the name plates of the furnace, outdoor AC unit, and evaporator coil. For the occupant behavior data collection, we observed thermostat settings at the time of the site visit and asked the participants about their historical thermostat settings (before the Wi-Fi thermostat was installed). For the environmental data collection, we recorded outdoor air conditions at the time of the power test.

Cadmus obtained trend data from Ecobee, the manufacturer of the installed thermostats. This data included time-stamped information on equipment run times, system status (cooling/heating/off), indoor and outdoor air conditions, and thermostat set points. The analysis was performed using trend data, recorded every five minutes, from March through October 2011.

We also contacted air conditioner manufacturers to obtain specification sheet data about the identified units at each visited site.

Calculation Methodology

Cadmus used Ecobee trend data (see example data in Appendix A) and data from the site visit to calculate electric energy savings on a site-by-site basis. Using the trend data, we first determined a relationship between equipment run time and the difference between outside air and thermostat set point temperature (ΔT). For each ΔT value we determined a percent runtime for the cooling system. We then used the true power test reading to adjust manufacturer data that related outside air temperature to system power for each specific unit. When manufacturer spec sheets were not available (as for older units), we used a default curve fit value that we had established in a previous Cadmus study by metering the true power and outside air conditions for existing units. An example of the power curve adjustment can be found in Appendix A.

The outside air versus thermostat set point temperature (ΔT) was easily calculated in the post-installation case because the Ecobee trend data included both temperatures over the season. In the pre-installation (baseline) case, the ΔT was calculated using the schedule and set point information taken from the participants' surveys. When this information was not available, we predicted a likely baseline set point from information recorded by the thermostat.[6] In the absence of participant responses about their typical setback/setup patterns, we assumed that the baseline set point applied to all hours.

The participants included in the electric savings analysis had a mix of programmable and non-programmable thermostats before the installation of the Wi-Fi thermostat. Of the 12 thermostats analyzed, six were previously programmable and six were previously non-programmable. For purposes of this analysis, the important distinction was not whether the participant had a

[5] Each thermostat controlled a different central air conditioning system.

[6] The thermostats record data including indoor and outdoor air temperature, which is available through Ecobee's web portal. Ecobee shared this data with Cadmus for analysis purposes.

programmable or non-programmable thermostat but how the thermostat was used. For example, a programmable thermostat may be held at one temperature throughout the cooling season (this was observed at three of 12 analyzed sites). By the same token, a non-programmable thermostat may be adjusted up and down on a daily basis by an attentive occupant (this was observed at one of 12 analyzed sites). For these reasons the baseline case was calculated based on schedule and set point information taken from the participants' surveys or predicted from thermostat information, as discussed above.

The difference in savings between sites whose prior equipment was a programmable thermostat and sites with a non-programmable thermostat was found to be minimal. Due to the small sample size no quantitative results were found comparing savings between programmable and non-programmable thermostats. Because thermostat installation savings rely on behavioral factors it is important for the analysis to know the previous schedule and set points whenever possible.

The resulting curve fit, which compares actual spot-checked outside air temperature to actual spot-checked true system power usage, is referred to as the adjusted curve fit. We used the adjusted curve fit to estimate unit power consumption by multiplying recorded run time (from trend data) by the calculated unit power at the outside air temperature recorded by the thermostat (also from trend data) over the cooling season.

To determine run time in the baseline case, we multiplied the probability that the system would run at a particular ΔT value by the time interval at each ΔT value through the season. The adjusted curve fit was used to predict system power consumption at that particular outside air temperature. To ensure a consistent comparison, we used the same methodology to forecast unit consumption in the post-installation case, and a percent savings was developed (percent reduction in run time). This percent savings was applied to the system power calculation to obtain savings for each site.

Some sites were excluded from the analysis because they lacked sufficient data; the specific reasons are listed in Table 3.

Table 3. Participant Screening for Electric Analysis

Site-Level Screening Criterion	Number of Participants Dropped
Thermostat did not record cooling data	2
Unable to complete spot metering while onsite	1
Poor regression characteristics impeded analysis	2
Total Thermostats Screened Out	5
Total Thermostats Used in Analysis	12

Process Evaluation

Cadmus conducted a process evaluation to assess how well the pilot program worked from the perspectives of program staff, contractors, and participants. The process evaluation also examined the influence of the Wi-Fi thermostat on participants' behavior, as well as on overall participant satisfaction. Cadmus conducted interviews with program staff, contractors, and participants as part of the process evaluation.

Program Manager Interview

Cadmus conducted an interview with the program manager at National Grid to evaluate program design and implementation. The interview focused on:

- Motivation for implementing the pilot program
- Goals for the program
- Marketing materials for the program
- Experience working with contractors

Contractor Interviews

Cadmus interviewed a manager and two installers from Gem Plumbing and Heating, the contractor that installed the Wi-Fi thermostats. These interviews discussed:

- Satisfaction with the program and delivery methods
- Ease of installation
- Wi-Fi thermostat saturation levels and common applications
- Clarifications needed to complete the program evaluation

Participant Surveys

Cadmus administered 25 surveys (meeting the 90% confidence and 15% precision level) after selecting a random sample from the pool of pilot program participants. Prior to the pilot program, eight of the surveyed participants had used a non-programmable thermostat and 17 had used a programmable thermostat. The surveys for participants were the same and differed only for specific questions about the previously installed unit.

The survey comprised a series of questions regarding program awareness, training and installation, system configuration, and program satisfaction. The survey also included questions about the type of thermostat, if any, the participant would have purchased without the pilot program. These questions are intended to determine the level of freeridership in the program.

4. Impact Evaluation Findings

Estimating Gas Savings

Table 4 shows the Wi-Fi thermostat gas savings, which averaged 110 therms per household. The per thermostat savings for the single thermostat installations are higher than the two thermostat installations. Since our billing analysis sample (n=66) averaged 1.35 Ecobee thermostats installed per household, the savings per thermostat is 82 therms. The calculation of a 90 percent confidence interval around the overall savings yields an estimate of 63 to 100 therms per thermostat. Each thermostat achieved 10% savings over the average annual pre-installation gas usage of 858 therms per household. Each participant household achieved 13% savings over the average (110/858 therms). When WI-FI thermostats replaced non-programmable thermostats the savings are 87 therms or 10% per thermostat, while when they replaced programmable thermostats the savings are 66 therms or 8% per thermostat.[7]

[7] Low sample sizes did not permit model estimation of savings into both quantity of thermostats installed and replaced thermostat type (non-programmable or programmable).

Table 4. Wi-Fi Thermostat Gas Billing Analysis Savings Summary

Billing Analysis Group	Number of Participants (Billing Analysis)	Savings (Therms per HDD)	Normal HDD TMY3	Savings Per Household (Therms)	Savings Per Thermostat (Therms)	Pre-Period Usage	Savings as % of Pre-Period Usage	90% Precision	Savings Lower 90% CI	Savings Upper 90% CI
1 Thermostat	43	0.01409	6,117	86	86	802	11%	31%	60	113
2 Thermostats	23	0.02513	6,167	155	77	964	8%	28%	55	100
Overall*	66	0.01794	6,135	110	82	858	10%	23%	63	100
Non-Programmable Thermostats	23	0.01837	6,146	113	87	890	10%	31%	60	113
Programmable Thermostats	43	0.01470	6,129	90	66	842	8%	34%	43	88

*The overall savings estimates are determined as the weighted average of the participants installing one thermostat and two thermostats. These do not necessarily equal the weighted average savings across programmable and non-programmable thermostats.

Table 5 through Table 8 present the regression output of the Wi-Fi thermostat models.

Table 5. Wi-Fi Thermostat Billing Analysis Regression Model Output (Single Thermostat)

Source	Analysis of Variance				
	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	56	6930.25229	123.75451	288.86	<.0001
Error	924	395.86028	0.42842		
Corrected Total	980	7326.11257			
Root MSE	0.65454		R-Square	0.946	
Dependent Mean	2.03626		Adj R-Square	0.9427	
Coeff Variance	32.14415				
Source	Parameter Estimates				
	DF	Parameter Estimates	Standard Error	t value	Prob. T
Average Intercept*	43	0.41035	0.42420	0.96	0.3371
AvgHDD	1	0.11742	0.01195	9.83	<.0001
PostHDD	1	-0.01409	0.00264	-5.33	<.0001
Jan	1	0.27711	0.1216	2.28	0.0229
Feb	1	0.36519	0.10252	3.56	0.0004
Mar	1	-0.03873	0.15168	-0.26	0.7985
Apr	1	-0.30679	0.23448	-1.31	0.1911
May	1	-0.09559	0.32779	-0.29	0.7706
Jun	1	0.06002	0.3876	0.15	0.877
Jul	1	0.00060453	0.40173	0	0.9988
Aug	1	-0.06839	0.39963	-0.17	0.8642
Sep	1	-0.23755	0.3631	-0.65	0.5131
Oct	1	-0.46314	0.26156	-1.77	0.0769
Nov**	1	-0.3668	0.15263	-2.4	0.0164

* Since we ran the model with a fixed-effects specification, each participant has a unique intercept. Due to the large amount of output produced when showing the model coefficients for each of the 43 intercepts, the model output in this table presents the average of the separate intercepts.

** The December indicator is not included in the model otherwise there would be perfect co-linearity with the intercept.

Table 6. Wi-Fi Thermostat Billing Analysis Regression Model Output (Two Thermostats)

	Analysis of Variance				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	36	5399.77855	149.99385	339.91	<.0001
Error	486	214.46053	0.44128		
Corrected Total	522	5614.23908			
Root MSE	0.66429		R-Square	0.9618	
Dependent Mean	2.49978		Adj R-Square	0.959	
Coeff Variance	26.57386				

	Parameter Estimates				
Source	DF	Parameter Estimates	Standard Error	t value	Prob. T
Average Intercept*	23	3.49219	0.73894	4.73	<.0001
AvgHDD	1	0.05258	0.02153	2.44	0.0149
PostHDD	1	-0.02513	0.00435	-5.78	<.0001
Jan	1	0.81605	0.17879	4.56	<.0001
Feb	1	0.48815	0.14415	3.39	0.0008
Mar	1	-0.98801	0.26382	-3.75	0.0002
Apr	1	-2.01597	0.4099	-4.92	<.0001
May	1	-2.65145	0.58801	-4.51	<.0001
Jun	1	-2.79124	0.69987	-3.99	<.0001
Jul	1	-2.86533	0.726	-3.95	<.0001
Aug	1	-2.91501	0.72139	-4.04	<.0001
Sep	1	-2.86028	0.65895	-4.34	<.0001
Oct	1	-2.44958	0.47118	-5.2	<.0001
Nov**	1	-1.30793	0.25634	-5.1	<.0001

* Since we ran the model with a fixed-effects specification, each participant has a unique intercept. Due to the large amount of output produced when showing the model coefficients for each of the 23 intercepts, the model output in this table presents the average of the separate intercepts.

** The December indicator is not included in the model otherwise there would be perfect co-linearity with the intercept.

Table 7. Wi-Fi Thermostat Billing Analysis Regression Model Output (Existing Non-Programmable Thermostats)

Source	Analysis of Variance				
	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	36	4729.55337	131.37648	333.17	<.0001
Error	484	190.85489	0.39433		
Corrected Total	520	4920.40827			
Root MSE	0.62796		R-Square	0.9612	
Dependent Mean	2.31921		Adj R-Square	0.9583	
Coeff Variance	27.07629				
Source	**Parameter Estimates**				
	DF	**Parameter Estimates**	**Standard Error**	**t value**	**Prob. T**
Average Intercept*	23	1.52294	0.54126	2.83	0.0046
AvgHDD	1	0.10138	0.01577	6.43	<.0001
PostHDD	1	-0.01837	0.00343	-5.35	<.0001
Jan	1	0.56511	0.15557	3.63	0.0003
Feb	1	0.47075	0.13263	3.55	0.0004
Mar	1	-0.34649	0.20740	-1.67	0.0954
Apr	1	-0.91062	0.31330	-2.91	0.0038
May	1	-1.01346	0.42724	-2.37	0.0181
Jun	1	-0.94073	0.50595	-1.86	0.0636
Jul	1	-1.0155	0.52487	-1.93	0.0536
Aug	1	-1.09273	0.52168	-2.09	0.0367
Sep	1	-1.18292	0.47561	-2.49	0.0132
Oct	1	-1.2323	0.34437	-3.58	0.0004
Nov**	1	-0.70872	0.20098	-3.53	0.0005

* Since we ran the model with a fixed-effects specification, each participant has a unique intercept. Due to the large amount of output produced when showing the model coefficients for each of the 23 intercepts, the model output in this table presents the average of the separate intercepts.

** The December indicator is not included in the model otherwise there would be perfect co-linearity with the intercept.

Table 8. Wi-Fi Thermostat Billing Analysis Regression Model Output (Existing Programmable Thermostats)

Source	Analysis of Variance				
	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	56	7569.11612	135.16279	277.62	<.0001
Error	926	450.82727	0.48685		
Corrected Total	982	8019.94339			
Root MSE	0.69775		R-Square	0.9438	
Dependent Mean	2.13282		Adj R-Square	0.9404	
Coeff Variance	32.7149				
Source	Parameter Estimates				
	DF	Parameter Estimates	Standard Error	t value	Prob. T
Average Intercept*	43	0.84523	0.50991	1.66	0.0969
AvgHDD	1	0.11026	0.01446	7.62	<.0001
PostHDD	1	-0.0147	0.00307	-4.79	<.0001
Jan	1	0.3189	0.13466	2.37	0.0181
Feb	1	0.3519	0.11101	3.17	0.0016
Mar	1	-0.17757	0.17615	-1.01	0.3137
Apr	1	-0.5617	0.27754	-2.02	0.0433
May	1	-0.45177	0.39842	-1.13	0.2571
Jun	1	-0.32689	0.47218	-0.69	0.4889
Jul	1	-0.35746	0.4895	-0.73	0.4654
Aug	1	-0.41083	0.48697	-0.84	0.3991
Sep	1	-0.56182	0.44278	-1.27	0.2048
Oct	1	-0.71291	0.31658	-2.25	0.0246
Nov**	1	-0.49409	0.17761	-2.78	0.0055

* Since we ran the model with a fixed-effects specification, each participant has a unique intercept. Due to the large amount of output produced when showing the model coefficients for each of the 43 intercepts, the model output in this table presents the average of the separate intercepts.

** The December indicator is not included in the model otherwise there would be perfect co-linearity with the intercept.

Estimating Electric Savings

The electric savings per thermostat averaged 104 kWh per year. However, since our electric analysis sample (12 thermostats, 11 participants) averaged 1.1 Ecobee thermostats installed per home, the savings per participant is 113 kWh. The average estimated pre-installation usage in the selected sample was 640 kWh per year, although the participants in this pilot program used less electricity, on average, than a typical residential customer in the region. Overall, the savings from the Wi-Fi thermostat were on average 16% of the estimated cooling season energy usage. Table 9 summarizes electric savings results.

Table 9. Wi-Fi Thermostat Electric Savings Analysis Savings Summary

Number of Thermostats (Included in Electric Analysis)	Number of Participants (Selected for Electric Analysis)	Average Usage, Pre (kWh)	Average Usage, Post (kWh)	Savings Per Thermostat (kWh)	Savings Per Participant (kWh)	Savings Per Thermostat (%)
12	11	640	536	104	113	16%

The average pre-installation usage is somewhat lower than the regional average due to lower than average typical run times. The equivalent full load hours (EFLH)[8] for Massachusetts, according to the 2012 MA Technical Reference Manual, is 360 hours. Cadmus calculated EFLH for each system examined in the electric savings analysis; the average EFLH across the sample was 170 hours. This lower EFLH value shows that the sample's usage is lower than regional averages due to reduced air conditioner run times. This may be due to sample self-selection for energy-efficient behavior (those interested in participating in energy-efficiency pilot programs may be more likely to have pursued energy-efficiency measures or operate their systems more efficiently than the general population).

As discussed in the Impact Evaluation Methodology section, these results do not differentiate between sites with a programmable thermostat baseline and sites with a manual thermostat baseline. This is due to the behavioral issues observed during site visits and surveys which showed that it is relatively common for a programmable thermostat to be used in such a way that the programmable functionality is ignored.

8 The equivalent full load hours (EFLH) represents the number of hours that an air conditioner that is designed exactly for the peak load would run at full load to satisfy the annual cooling load.

5. Process Evaluation Findings

Program Awareness

National Grid recruited eligible participants to the Wi-Fi Programmable Controllable Thermostat Pilot Program through advertisements e-mailed to its customers. In Massachusetts, survey participants were asked about the e-mail and how the description of the program encouraged them to participate. Participants reported they were interested in:

- Testing out a new technology at no cost
- Conserving energy
- Saving money on energy bills
- Having more control over their thermostat, including the ability to change the unit remotely

Overall, survey respondents reported that the enrollment process was very easy. Customers who were eligible and interested in participating in the program filled out a short online application that was submitted to National Grid. A few respondents made suggestions for improvements. Some respondents suggested that in the future, the program administrator should:

- Clarify that two-zone systems are covered in the program
- Recruit participants through phone calls instead of e-mail
- Provide follow-up contact between application submission and approval

Training and Installation

National Grid selected Gem Plumbing and Heating to install the Wi-Fi programmable controllable thermostats. The program manager reported that the communication and coordination process has gone smoothly with Gem. National Grid, after receiving and accepting a customer's application, sent it to Gem who in turn contacted the participant. The turnaround time for this application process was about a one week. The program manager reported receiving no negative feedback from program participants about this process.

Cadmus interviewed a manager and two installers with Gem. Gem was provided with contact names and addresses after National Grid screened participants for eligibility. Prior to installation, installers received one session of training from National Grid; they reported the training was straight-forward and helpful. The Gem manager and installers also described the installation process as very smooth. Gem received calls from only two customers requesting further assistance with their thermostat. One thermostat was faulty and had to be replaced. The other customer had damaged wiring that was affecting use of the thermostat. The Gem manager was impressed at how few call-backs they received even though over 100 units were installed through the program.

Participant survey respondents were asked about the installation process and reported general satisfaction. About half of those surveyed reported that the thermostat installer explained how to use both the thermostat and the Ecobee Website. About 36% of respondents (9 of 25) reported that the installer explained how to use the thermostat only. Only one respondent reported that the installer did not explain how to use either the thermostat or the Website. Respondents also reported that the installer referred them to additional reference sources such as the user's manual or a call number. One installer reported that he showed the participants how to use both the thermostat settings and the Website. The other installer did not specify if he explained how to use the Website in detail, but he expressed that the participants he interacted with were "tech savvy."

About half of the respondents reported that the contractor helped set up the thermostat schedule and set points; the majority of these respondents said the contractor did so at the unit itself. The other half of the respondents set up the schedule and set points themselves and said they generally did so on the day of installation. The majority of these participants (9 of 13) used the Website to set up the thermostat.

Survey respondents were asked what was most helpful about the information given during the thermostat and Ecobee Website training. Answers included:

- Instruction on how to set the different programs
- Explanation on how to temporarily alter settings
- Detailed description of the vacation feature

The majority of respondents reported that they did not require any explanation on how to use the thermostat or Website and that they easily understood the device. When asked to rank their satisfaction with the installation and training process on a 0 to 10 scale (where 0 is extremely dissatisfied and 10 is extremely satisfied), the majority (14 of 25) categorized their satisfaction as a 10 (Figure 1).

Figure 1. On a scale from 0 to 10, where 0 is extremely dissatisfied and 10 is extremely satisfied, how would you rate your satisfaction with the installation and training process?

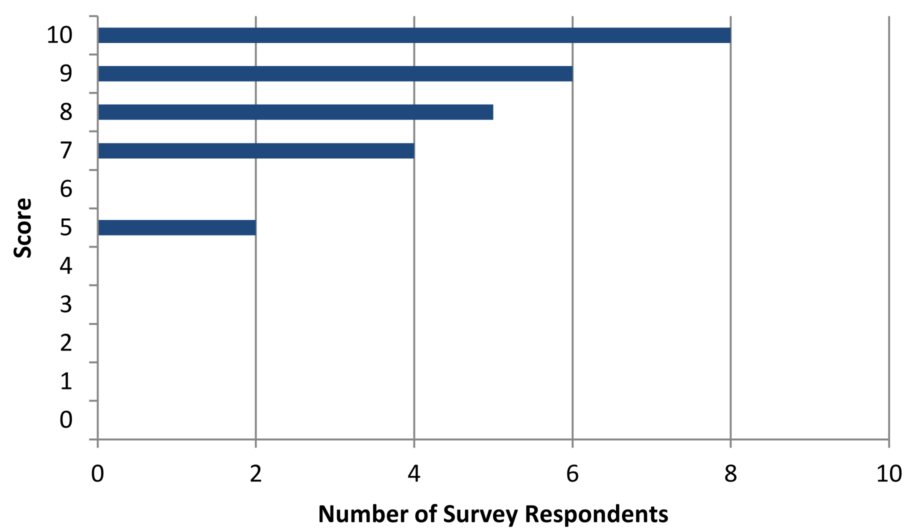
The only negative response came from one respondent who reported a lack of necessary information about updating the system. This individual explained that he received e-mails about updates but did not receive direct help in the training process. Although he ranked the training process a 2, he ranked the installation process a 10.

Participants suggested that the training and installation process could be improved if the installer:

- Spent more time explaining technical aspects of thermostats at installation
- Provided step-by-step instructions on how to use the Website

Survey respondents were asked about their experience with the Ecobee thermostat Web portal. They were asked to rank the Web portal's ease of use on a scale from 0 to 10, where 0 is very difficult and 10 is very easy. The majority of respondents ranked the Web portal's ease of use favorably, with 19 respondents assigning a ranking between 8 and 10 (Figure 2).

Figure 2. On a scale from 0 to 10, where 0 is very difficult and 10 is very easy, how would you rate the Ecobee Thermostat Web portal's ease of use?



Survey respondents were also asked if they had any suggestions to improve the Web portal. Respondents suggested that the Web portal should:

- Send notifications whenever reprogramming occurs
- Improve visibility of button functions
- Provide more flexible programming capability, such as a time resolution that is more frequent than every half hour and alternative week programming
- Add a FAQ page in the help tutorial
- Improve Ecobee's Web portal for systems with two thermostats
- Include more days in the reports or a one-month range[9]

[9] Although one participant responded that reports should provide data for a time period greater than one month, the Web portal does provide the ability to access reports over a year period. This feedback from the respondent is likely due to a misunderstanding of what data the Web portal provides, but is valuable in identifying potential Web portal improvements (i.e., more user-friendly reports).

System Configuration

Survey respondents were asked a series of questions to compare the system configuration of their previous thermostat to their new Wi-Fi thermostat. The majority of respondents set schedules and set points on their new thermostat for when they are at home, away, asleep, and/or awake.

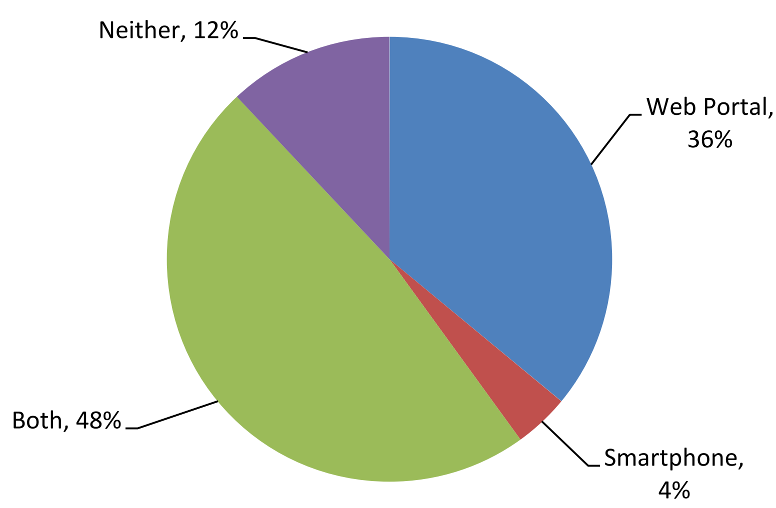
Participants were asked specifically how they determined which schedule and set points to use for their new Wi-Fi thermostat. The majority of respondents who previously owned a programmable thermostat indicated that the contractor programmed their new Wi-Fi thermostat to the same schedule as the old unit. Five of these 17 respondents subsequently adjusted the schedule of the new thermostat. Participants stated that their reasons were to:

- Reduce heat usage based on data from the thermostat
- Program a different temperature schedule for weekends
- Warm the house before waking up and before coming home from work
- Set different upstairs and downstairs temperatures

Wi-Fi Features

Participants were asked if they ever access thermostat settings through the Web portal or a smartphone app (Figure 3). The majority of respondents (12 out of 25) reported they access thermostat settings through both the Web portal and the smartphone app. Nine respondents reported they have accessed thermostat settings through the Web portal (but never the smartphone app), one respondent reported they access settings through the smartphone app (but never the Web portal), and three respondents reported they access settings through neither the Web portal nor the smartphone app.

Figure 3. Do you ever access thermostat settings through the Web portal or a smartphone app?



Participants were also asked how the Wi-Fi capability had changed their approach to regulating temperature in their home compared to their previous thermostats. The majority (21 out of 25 people) indicated that their new Wi-Fi thermostat changed their approach to regulating temperature in their home. Changes in approaches included:

- Programming the thermostat to set different temperatures for different weekdays
- Using the smartphone app to set the thermostat temperature when away from home
- Checking the Web portal to see reports of energy usage and adjusting temperature accordingly
- Checking the system when away from the home for extended periods of time

The vacation feature is another popular option, according to survey respondents. Fourteen of 25 respondents indicated that they used the vacation feature to set back their thermostat. Of those fourteen respondents, the majority (six individuals) reported that they use the vacation feature when they are away from the home for more than three nights. Five individuals reported that they use the vacation feature every time they are away from their home overnight. Only one person used the vacation feature when they are away from their home for more than a week.

Several participants noted the ability to remotely alter their household's temperature as one of the most useful features. Seventeen of 25 respondents indicated that they interact with the Web portal when they are away from the home, typically to check the outside or inside temperature (11 respondents) or to adjust settings (12 respondents). Survey respondents who claimed they do not interact with the thermostat when they are away from the home reported it is not necessary because they are not away from the home for long periods of time.

Respondents were asked if they view the reports from the thermostat and, if so, how this review affects their energy usage. About half of the respondents (13 of 25) reported that they view the reports, but the majority of these respondents (10 of 13) claimed it has not significantly affected their energy usage. Most of the participants who view the reports claimed they do so out of curiosity and only three of those respondents claimed it affected their use of the thermostat.

The majority of respondents also reported that the Wi-Fi thermostat is easier to set than their previous thermostat; only one person reported that it is not easier to set. Explanations given for the Wi-Fi thermostat's ease of use include:

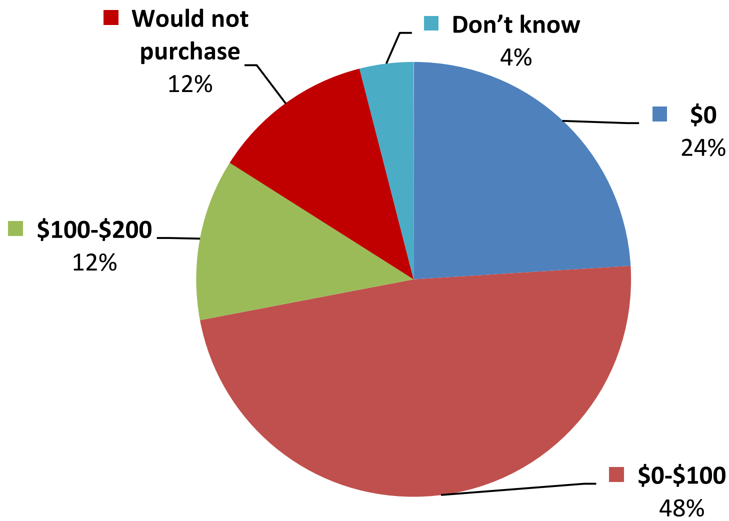
- Ability to set a higher resolution in terms of time
- Ability to set the thermostat from outside the home
- Ease of scheduling vacation mode
- User-friendly interface

Direct Install Net-to-Gross

The pilot program has a net-to-gross value of 0.96. Eighty-four percent of respondents (21 of 25) reported they were not planning to purchase a new thermostat and 16% (4 of 25) of respondents reported they were. Of the four people planning to purchase a new unit, one reported he was planning to purchase a Wi-Fi programmable thermostat. The other three were planning to purchase programmable units (all had previously owned non-programmable thermostats). When asked why they were not considering a Wi-Fi programmable thermostat, two of the three reported they had not heard of Wi-Fi thermostats before. The third respondent reported he thought his household did not need the additional functionality of a Wi-Fi thermostat.

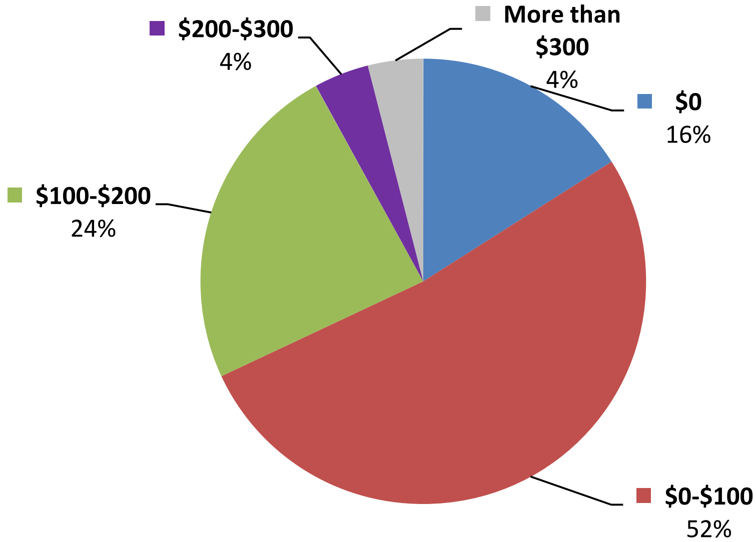
Respondents were also asked about their willingness to pay for a Wi-Fi programmable thermostat before they learned about the National Grid pilot program. The majority of respondents (12 of 25) reported that they would have paid between $0 and $100 (Figure 4).

Figure 4. If the cost of a non-Wi-Fi programmable thermostat was $200 including installation, how much more would you have been willing to pay for the Wi-Fi feature before you learned about the National Grid Wi-Fi thermostat pilot?



Survey respondents were then asked about their willingness to pay for a Wi-Fi programmable thermostat *after* they learned about the National Grid pilot program. More respondents reported a willingness to pay more money than if they had never heard about the program. For example, 52% of respondents (13 of 25) would pay between $0 and $100 and 24% of respondents (6 of 25) would pay between $100 and $200 (Figure 5).

Figure 5. Now that you have had a chance to use the Wi-Fi thermostat, if the cost of a non-Wi-Fi programmable thermostat was $200, how much more would you have been willing to pay for the Wi-Fi feature?

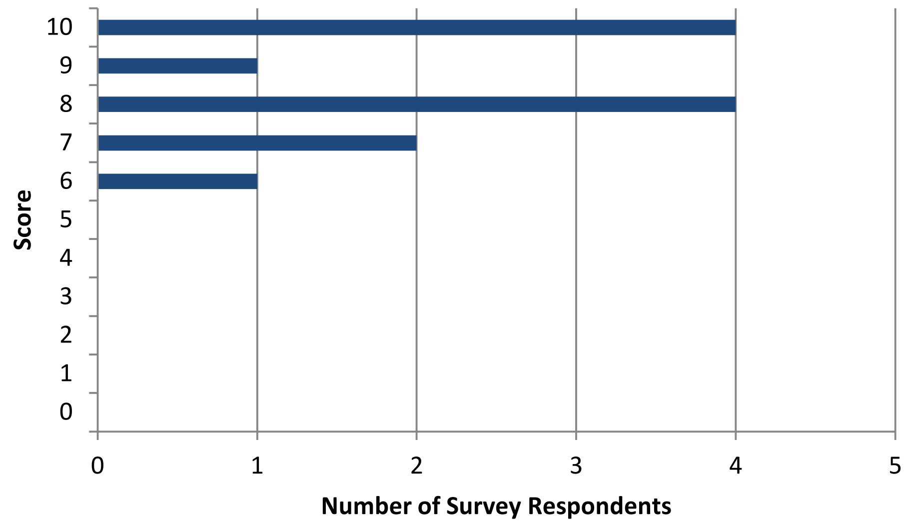


Energy Savings

Survey respondents were asked if they noticed a reduction in energy bills since participating in the pilot program. Nearly half of respondents (12 of 25) reported that they did notice a reduction in their bills, while only seven respondents reported they did not notice a difference. Other respondents did not know if they had seen a change.

Of those respondents who reported that they observed a change in their energy bills, the majority rated their satisfaction with the changes highly (Figure 6).

Figure 6. On a scale from 0-10, where 0 is "extremely dissatisfied" and 10 is "extremely satisfied," how satisfied are you with the energy savings you have seen by participating in the National Grid Wi-Fi thermostat pilot?



Non-Energy Benefits

Respondents were also asked about the non-energy benefits they observed in their households over the course of the pilot program. The majority reported that they did not observe a change in thermal comfort. Those who did report a change in thermal comfort rated it as a positive change; no respondent reported a negative change.

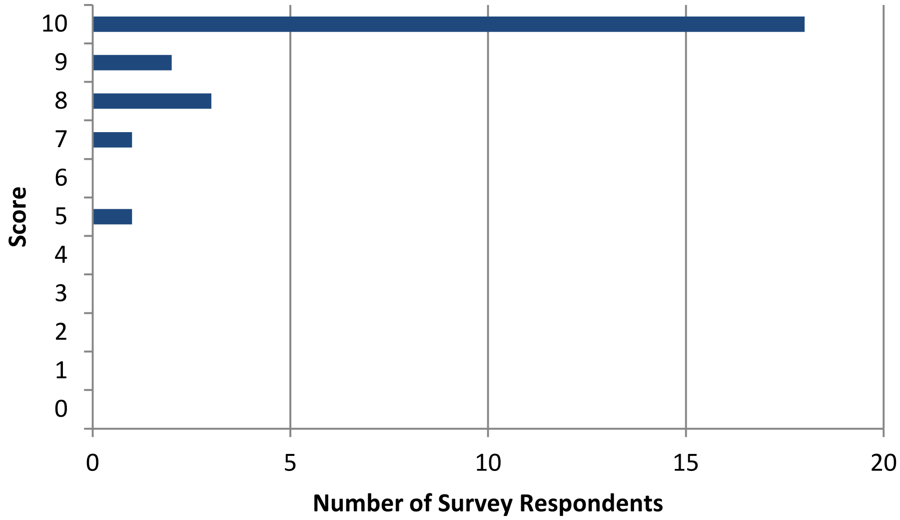
Although half of the respondents reported that they did not experience any non-energy benefits since participating in the program, some respondents did notice a change. Several reported that since installing the thermostat, they have:

- Become more aware of the temperature in their home
- Become more likely to adjust the temperature due to the thermostat's ease of use
- Observed household light usage and outside weather reports more closely

Program Satisfaction

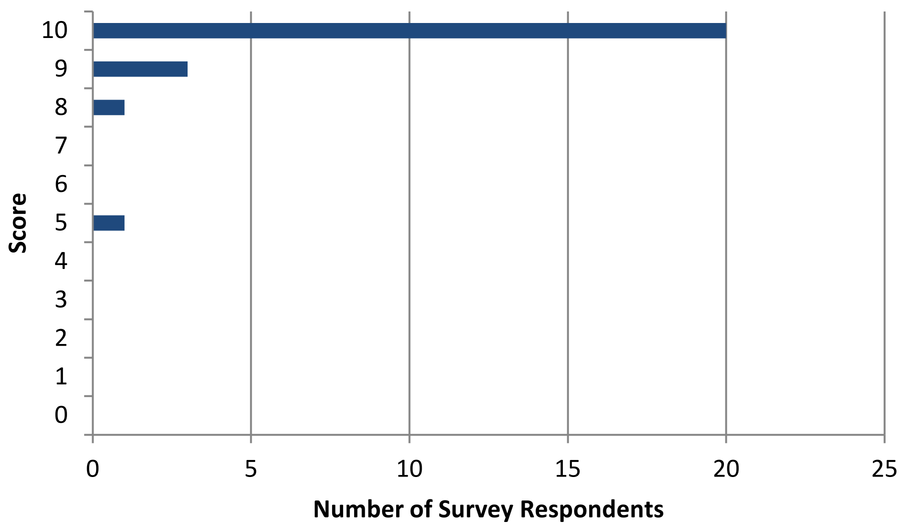
The majority of survey respondents rated their satisfaction with the Wi-Fi thermostat highly. The majority of people (18 of 25) rated their thermostat a 10 on a scale from 0 to 10 (Figure 7).

Figure 7. On a scale from 0 to 10, where 0 is extremely dissatisfied and 10 is extremely satisfied, how satisfied are you with your Wi-Fi thermostat?



Survey respondents' satisfaction with the program follows the same general pattern as their satisfaction with the thermostat unit, although respondents overall rated the program slightly higher than the thermostat (Figure 8).

Figure 8. On a scale from 0 to 10, where 0 is extremely dissatisfied and 10 is extremely satisfied, how satisfied are you with the National Grid Wi-Fi Thermostat Pilot Program?



Survey respondents suggested that the program could be improved by:

- Expanding the program to accept more participants from a wider area
- Improving the Web interface for households with two thermostats (i.e., making each thermostat's activity separately distinguishable)

- Providing more marketing materials (i.e., press releases, ads) to the general public
- Creating online tutorials or videos for participants who are not as knowledgeable about technology

6. Conclusions and Recommendations

Impact Evaluation

Both gas and electric savings were achieved through the pilot program. Based on our evaluation Cadmus recommends the following:

- **The gas savings for single thermostat installations (11% per thermostat) are considerably larger than for two thermostat installations (8% per thermostat)**. The multiple thermostats likely are controlling the same heating system but in a different lower usage zone or possibly serving a secondary heating system.
  - **Recommendation:** If a full scale Wi-Fi thermostat program is rolled out, consider these saving differentials during the program design and planning process.
- **The gas savings for non-programmable thermostat replacements (10% per thermostat) are larger than for programmable thermostat replacements (8% per thermostat).**). As expected when the Wi-Fi thermostats are replacing programmable thermostats, the percent savings are lower than for non-programmable thermostats. The Wi-Fi savings for programmable thermostat replacements form the lower bound of the heating seasons savings expected from the Wi-Fi thermostat installations.
  - **Recommendation:** If a full scale Wi-Fi thermostat program is rolled out, use separate percent savings estimates for heating for non-programmable or programmable thermostats.
- **The electric savings for non-programmable thermostat replacements are effectively equal to those for programmable thermostat replacements.** Not all occupants use the full functionality of their programmable thermostats. In cases where an occupant has a programmable thermostat but declines to use the schedule and set point functionality the thermostat is effectively a non-programmable thermostat.
  - **Recommendation:** If a full scale Wi-Fi thermostat program is rolled out, record the baseline set points and schedule as well as recording whether the baseline thermostat was programmable or non-programmable. Use this information to assess whether the baseline thermostat behavior was equivalent to a programmable thermostat or not.
- **Electric savings associated with Wi-Fi enabled thermostats vary significantly from one house to another**. The savings are very dependent on occupant behavior and baseline set point information. This baseline set point information was based on participant recollections of prior set points, which may be incorrect. To improve evaluability and increase confidence in savings, pre- and post-metered data are preferred.
  - **Recommendation:** Install energy metering equipment on air conditioner and air handler units belonging to program participants covering a period including pre-installation and post-installation time periods. Use this information to estimate program savings. This would increase confidence in the program savings estimate by showing how much energy is consumed for cooling prior to thermostat installation. The exact savings for each site could be calculated without making baseline assumptions or relying on participants to remember prior set points and schedules.

- **For some participants the energy savings benefits of a Wi-Fi enabled thermostat are similar to those of a standard programmable thermostat.** Whether a participant saves more energy with a Wi-Fi thermostat than they would with a programmable thermostat is difficult to quantitatively predict as the savings are reliant on participant behavior.
  - **Recommendation:** Determine the portion of participants that are using the programmable functionality of their thermostats when the Wi-Fi thermostats were installed. When a participant installs a Wi-Fi thermostat gather information about the baseline system including thermostat type and program status for future program evaluation purposes.

Process Evaluation

The process evaluation revealed that, in general, program participants and contractors were satisfied with their experiences in the program. However, based on participant responses, Cadmus recommends several actions for future Wi-Fi pilot programs.

- **Participant training process.** Although there was general satisfaction among participants regarding training, a few suggested a more intensive training session.
  - **Recommendation:** The installer should ask if the participant would like the installer to spend more time explaining technical aspects of thermostats at installation and/or to provide step-by-step instructions on how to use the Web portal. The participant would then have a chance to get more in-depth training if desired.
  - **Recommendation:** For participants who require more assistance operating the Wi-Fi thermostat, online tutorials or videos should be made available. Links to these tutorials on the Web portal could be distributed at installation.
- **Web portal.** Survey respondents were asked about potential improvements to the Web portal. Most respondents used the Website and reported that it was easy to use. Several participants recommended improvements.
  - **Recommendation:** The Web portal interface should be more user-friendly and this may be facilitated by improving the visibility of button functions and thereby lessening confusion when navigating the Website. The Web portal's help tutorial should also have a highly visible link to a FAQ page to answer common questions. The Web portal should be easier to use by households with two thermostats so each thermostat's activity is distinguishable.
- **Program processes.** In general, participants expressed satisfaction with the Wi-Fi pilot program processes. Only a few participants made suggestions for program improvements.
  - **Recommendation:** A few participants noted that most of their acquaintances who are also National Grid customers were not aware of the Wi-Fi thermostat pilot program. National Grid should provide more marketing materials, such as press releases or bill inserts, to increase awareness of the program.

7. Appendix A

Table 10. Example Ecobee Thermostat Data Export

Date	Time	Program Mode	Cool Set Temp (F)	Heat Set Temp (F)	Current Temp (F)	Current Humidity (%RH)	Outdoor Temp (F)	Outdoor Humidity (%RH)	Cool Stage 1 Run Time (sec)	Cool Stage 2 Run Time (sec)	Heat Stage 1 Run Time (sec)	Heat Stage 2 Run Time (sec)	Fan Run Time (sec)
5/24/2011	21:15:00	Home	75	45	73.7	40	73	66	300	0	0	0	300
5/24/2011	21:20:00	Home	75	45	73.6	41	73	66	300	0	0	0	300
5/24/2011	21:25:00	Home	72.2	54.3	73.7	40	73	66	300	0	0	0	300
5/24/2011	21:30:00	Sleep	70	62	73.7	40	73	66	300	0	0	0	300
5/24/2011	21:35:00	Sleep	70	62	74.1	41	73	66	300	0	0	0	300
5/24/2011	21:40:00	Sleep	70	62	74.2	40	71.1	68	300	0	0	0	300
5/24/2011	21:45:00	Sleep	70	62	74.1	40	71.1	68	300	0	0	0	300
5/24/2011	21:50:00	Sleep	70	62	74.1	40	71.1	68	300	0	0	0	300
5/24/2011	21:55:00	Sleep	70	62	74	40	71.1	68	300	0	0	0	300
5/24/2011	22:00:00	Sleep	70	62	73.9	40	71.1	68	300	0	0	0	300
5/24/2011	22:05:00	Sleep	70	62	73.7	39	71.1	68	300	0	0	0	300
5/24/2011	22:10:00	Sleep	70	62	73.3	40	71.1	68	300	0	0	0	300

Figure 9. Condenser Power Curve