Programmable Thermostats: Once More Up the Roller Coaster

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ABSTRACT

Do programmable thermostats save energy, or not?

The billing analyses (RLW 2007, Recherches et Sondages 2007) performed in 2007 took us to the top of the hill by suggesting a high, positive energy savings for residential programmable thermostats. Since then we've been in free-fall, with at least four billing analyses suggesting that savings are unmeasurable (or zero).

Some of the authors had begun to consider the 2007 study an anomaly, and began suggesting that programmable thermostats don't save energy—for years. But now we have another positive result.

A recent billing analysis of 900 programmable thermostats showed highly statistically significant, positive energy savings for both electric and natural gas heated homes. Further, the nature of the program design—in which the thermostats were direct-installed both in large numbers and only in cases where a non-programmable was there before—seems to have played a major role in increasing the per-thermostat savings, which then makes this program more evaluable using billing analysis than others have been.

Come walk through the history of programmable thermostat evaluations and consider the implications of this new result for the future of residential retrofit program design and evaluation.

Introduction

Programmable thermostats—that energy efficiency program stalwart, especially for gas programs[1]—have gotten a bad rap. After a series of billing analyses failed to find savings, EPA suspended the specification for ENERGY STAR® programmable thermostats in 2009. By 2016 some programs were cutting them from the lineup, and others started planning to, giving up their seat to their fancy (and expensive) “smart” and wi-fi cousins. The authors themselves must plead guilty to encouraging programs to discontinue programmable thermostats (p-stats).

However, around 2005, National Grid Rhode Island designed a program called EnergyWise, which uses careful contractor selection and replacement guidelines to maximize the likelihood that every single p-stat replaced will save energy. And it worked. Even though the results were produced with two stage PRISM (Fels, M.F. 1986 & 1995), which was chosen because of its rigor, we still ran the model three different ways just to make sure we weren't dreaming. It was true.

[1] Electric heating (and some cooling) savings have been important as well, but p-stats have been a central component of most gas programs for decades.

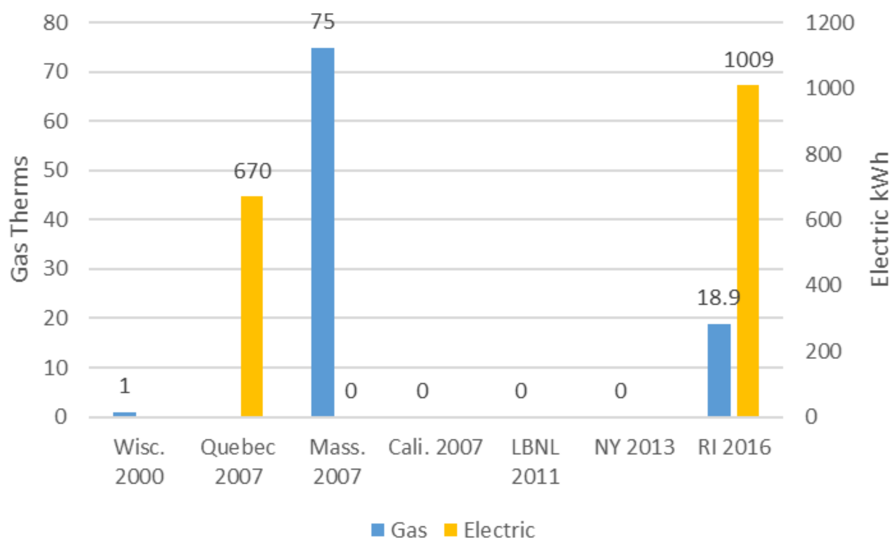

Figure 1. The Programmable Thermostat Roller Coaster (Heating Therms and kWh per Household)

This paper presents the findings of the evaluation of this program (DNV GL 2016), which found highly statistically significant savings estimates for regular-old programmable thermostats in both electric and gas heated homes.

But first, some background.

A History of Programmable Thermostats

Programmable thermostats (p-stats) are designed to save natural gas and/or electricity for heating in residential and commercial buildings by setting back the heating temperature to a lower temperature in the winter when areas are unoccupied or when residents are asleep.[2] Before the existence of p-stats, occupants had to remember to turn their thermostat down when leaving a space or going to sleep. With p-stats, they can program the thermostat once for their regular schedule and forget about it, overriding it when they happen to be home or awake when the heat would otherwise be set back.

P-stats can save energy because they provide additional functionality to the occupants by providing the ability for programming. They seldom cause additional energy usage because they do not take any functionality away that occupants had previously. Occupants can still set back the thermostat manually. However, when programmed correctly, p-stats set back the temperature for them and thus reduce the risk that they will forget or choose not to do so on any given day. Given that the measured savings across many programs has not met expectations, there has been some speculation that a small percentage of occupants who were extremely diligent about setting back their old-style thermostats actually use more energy when p-stats are installed because they pre-heat their spaces before they arrive or wake up, thus adding an extra 30-60 minutes of non-set back time daily. However, there is no evidence (and the question has been asked in multiple evaluations) to suggest that a large percentage of occupants fall into this diligent user category.

For these reasons, debates around energy savings associated with p-stats have centered around how much energy they save, not whether they save energy. Doubts about the magnitude of energy savings revolve around two difficult-to-overcome sources of uncertainty, one behavioral and one engineering-based:

[2] Savings may also occur in the summer for cooling, but cooling savings are outside the scope of this study.

1. The percentage of p-stats that are actually programmed, and whether new occupants learn to program the p-stats left behind when the old occupants leave.
2. The amount of energy saved by setting back temperatures in buildings with different heating systems and thermal characteristics.

Evaluation Success Factors

For years, energy efficiency program evaluators have attempted to estimate natural gas savings associated with programmable thermostats in residential and commercial buildings using a variety of methods. The quality and statistical significance of p-stat savings estimates have been found to be improved by each of the following factors:

1. Direct measurements of natural gas usage, as opposed to indirect measurements of temperatures or set points.
2. Comparison of pre-installation and post-installation data from the same premise, with sufficient pre- and post-installation data to establish a difference.
3. Comparison of the population participating in a p-stat installation program to a matched control group of nonparticipants.
4. Large sample sizes.
5. A minimum of variability in usage caused by factors other than the p-stat, such as other natural gas using appliances.
6. Additional data to suggest whether participants made other changes to their space during the analysis period, such as installing a new furnace or boiler.

Because field data collection of natural gas usage at the appliance or household level is generally cost-prohibitive (Success Factor #1), and because it is challenging to find participants who will submit to a study prior to the installation of p-stats which would allow for the collection of pre-installation data (#2), analyses of p-stat energy savings have generally relied on customer bills and Billing Analysis, though none of these studies have yet been able to use interval data.

Because residential buildings are much more numerous than commercial (#4), are similar to one another in their usage patterns thus making it easier to find a matched control group (#3), and because common residential usage patterns are well-understood (#5), most studies of p-stats have been performed with residential homes.

Despite these advantages, results from residential billing analysis studies have been inconsistent and often inconclusive.

The following six studies represent a sample of p-stat billing analysis-based evaluations. While more certainly exist, these are the ones we know about and have seen cited. They all attempted to estimate natural gas or electric heating savings from residential p-stats over the past sixteen years using billing analysis. The second and third study found statistically significant savings estimates of 670 kWh and 75 therms per household, respectively. The other studies were inconclusive and did not find statistically significant savings estimates.

1. Energy and Housing in Wisconsin: A Study of Single-Family Owner-Occupied Homes. Energy Center of Wisconsin, 2000.
2. Évaluation du programme des thermostats électroniques - marché existant 2004 à 2006. Prepared by Recherches et Sondages, October 2007.
3. Validating the Impact of Programmable Thermostats. Prepared for the GasNetworks by RLW Analytics (now DNV GL). January 2007.

4. 2004/2005 Statewide Residential Retrofit Single-Family Energy Efficiency Rebate Evaluation. Prepared for California's Investor-Owned Utilities by Itron, Inc., 2007.
5. Measuring the Usability of Programmable Thermostats. Lawrence Berkeley National Laboratories. From CS Week: April 25, 2011.
6. NYSEG/RG&E Residential Gas Process and Impact Evaluation. Prepared by KEMA, Inc. (now DNV GL). April 2013.

The authors do not have detailed information about the program designs used by most of the implementers of the programs evaluated above studies. In one case for which savings were not found, it is known that the implementer used a high TRM-deemed savings value as justification to offer programmable thermostats at every opportunity, often for free or in replacement of existing programmable thermostats. As we'll see, effective program design has the potential to make a huge difference in savings.

Scope

This paper presents the p-stat results from the impact evaluation of the 2015 single family EnergyWise program, completed by DNV GL. National Grid Rhode Island designed and manages the EnergyWise programs.

Methodology

Let's be honest. The "methodology" that matters here is the program design methodology that saved enough energy per thermostat to be evaluable. The way that National Grid managed this program maximized per-thermostat savings. Rather than offering thermostats to any customer, they only gave them to customers who had an existing non-programmable thermostat and were not replacing a furnace or boiler at same time. For this reason, per-thermostat savings are significant and therefore measurable using affordable methods.

We'll start by describing this program design.

EnergyWise Program Design

EnergyWise consists of a single family and multifamily combination direct-install and renovation program. For single family residents (the focus of this paper), contractors approach landlords or tenants and offer to replace existing equipment in their homes, including:

- Programmable thermostats
- Light bulbs (historically CFLs, now LEDs)
- Outdoor CFL fixtures
- Faucet aerators and showerheads
- Smart strips
- Refrigerator brushes
- Pipe insulation

The key to the success of this program is the rigorous contractor selection, installation requirements, and verification processes.

- **Contractors**: For the initial years of the program, a trusted contractor (RISE Engineering) performed all direct installations, setting a strong pattern for consistent program rule adherence and quality. Over the past three years, other pre-vetted contractors have been allowed to participate under the supervision of RISE.

- **Program Requirements**: Under this program, equipment must be installed by the contractor, and cannot be left behind for the resident to install. Light bulbs are only ever allowed to replace an existing incandescent or halogen bulb. Programmable thermostats are only ever allowed to replace an existing non-programmable thermostat.
- **Program Verification**: This program is managed by RISE, and 10% of sites are verified through random on-site inspections.
- **Target market:** The implementers target customers who would benefit from (or specifically request) a pstat. During the assessment the auditor interviews the customer to get a sense of how they are using their energy and if a pstat is a good fit. A family with two working parents on a regular 8-5 schedule would be a good candidate. Someone that is home all day may not be well suited.
- **Training**: The auditor/technician shows the customer how to program the pstat. In the cases of elderly and less tech savvy customers the technician will likely do the full programming for them.

This program design takes additional effort and cost to run compared to a program with less-strict procedures and rules, which reduces its cost-effectiveness slightly. However, as this study showed, this additional effort makes up for the cost by increasing the probability that every installed device saves energy, thus increasing the likelihood that savings are evaluable using billing analysis (the cost-effective method of choice for rigorous large-sample gas program evaluation).

Evaluation Methodology

The EnergyWise evaluation used a combination billing analysis / engineering adjustment approach for the EnergyWise program.[3] While the program evaluation included savings estimates for all measures, some of the most notable results were the savings from programmable thermostats.

We developed initial estimates for the program as a whole, and for measures which showed statistically significant savings, using billing analysis. For measures which did not show statistical significance, we adjusted the results using an engineering-driven approach so that the total amount of program savings added up to the overall total found by the billing analysis.

Billing Analysis

The billing analysis consisted of a two-stage approach:

- The first stage involved site-level modelling
- The second stage applied a difference-in-differences method to measure program savings overall and by impact group (treatment and control).

This approach estimates gross energy savings and relies on a control group consisting of all subsequent program participants (those who participated in the program in a later year, and are thus similar to those who participated in the evaluation year) to control for non-program related change. The method used in this evaluation is compliant with the International Performance Measurement and Verification Protocol (IPMVP) option Method C, Whole Facility, and was recently published in the U.S. Department of Energy's Uniform Methods Project (UMP) Whole-Building Retrofit Evaluation Protocol.

[3] In order to avoid confusing terms, the billing analysis attempted to use a statistically adjusted engineering (SAE) approach, which is a type of statistical model. This is distinct from the "engineering adjustments" made to the final billing analysis result, discussed below.

We also produced a Statistically Adjusted Engineering (SAE) regression with dummy variables for each impact group and the corresponding expected savings. The inclusion of both impact group savings and dummy variables minimizes understated estimates of savings due to errors from omitted variable bias and allows us to estimate savings from the different impact groups. For this analysis, however, the SAE results were not significantly different from the standard model either in savings or precision, and so were not included in results.

Table 1. Customers used in billing analysis

Data Disposition	Count	
	Elec (kWh)	Gas (therm)
Initial no. of accounts		
Participant Group	9,898	2,734
Comparison Group	11,626	2,746
Accounts removed for insufficient data and participants that started installations before 2014		
Participants removed	4,721	1,021
Comparison group removed	5,325	1,242
Accounts removed for other data issues*		
Participants removed	212	120
Comparison group removed	356	121
Final analysis data**		
Participants	4,965	1,593
Comparison Group	5,945	1,395

* This category includes participants who: Have no more than two estimated reads, have reads in the electric billing data and no more than 3 zero reads in the gas billing data, are outliers based on site level modeling, or are customers which have poor fits for normalized annual consumption.

** The analysis for gas included 2014 participants that also installed measures in 2015

Engineering Adjustments. Our evaluation approach relegated engineering work to the supporting role of assessing the impacts of measures unable to be quantified in the billing analysis. A key part of this was to have the final estimate of all measure level savings fit under the estimates for the program overall as determined in the billing analysis. This was done in two stages, described here:

1. Scale the savings estimates of all billing analysis measure categories to match the overall program savings billing analysis results. This involves two parallel steps, as follows:
    a. Assign savings to measures in the sample which did not receive statistically significant billing analysis savings estimates based on the proportion of tracking savings associated with that measure category in the sample.
    b. Adjust savings for both statistically significant and non-statistically significant measure categories proportionally so that the total savings matches the program-wide billing analysis result at the population level.
2. Apply the savings estimates created above for billing analysis measure categories to specific measures where requested.

In brief, the billing analysis produced savings results for the program overall, and statistically significant savings for certain individual measures and groups of measures. The engineering calculations then made sure that all measures were allocated an appropriate amount of savings (generally less than those which had achieved billing analysis statistical significance), and that all the estimates together added up to the total.

Results

The whole-home billing analysis results are as follows: Table 2 shows the overall household savings from the EnergyWise program as a whole, which includes programmable thermostats.

Table 2. Overall results by fuel type from difference of differences model with comparison group

Fuel	N	Estimated Savings per Household	Standard Error	Precision @ 90% Confidence	Pre-NAC per Household*	Savings as Percent of Pre-NAC
Electric (kWh)	4,965	434	42.40	±16%	9,274	4.7%
Gas (therms)	1,593	91	6.69	±12%	1,100	8.2%

* Pre-Installation Normalized Annual Heating Consumption (Pre-NAC). This represents the consumption that each customer would have used in the pre-installation case during a Typical Meteorological Year.

Table 3 shows the subset of results from Table 2 that relate to programmable thermostats. Note that most households did not include a programmable thermostat, particularly electric households.

Table 3. Overall results by fuel type from difference of differences model with comparison group for p-stats

Measure Group	N	Estimated Savings per Household	Std Err	Precision @ 90% Confidence	Pre-NAC per Household	Savings as Percent of Pre-NAC
Electric (kWh)	47	1,222	333	±45%	16,662	7.3%
Gas (therms)	500	30.2	8.8	±48%	1,148	2.6%

As discussed above, results for specific measures had to be adjusted during the engineering-driven scaling process, and broken out from the per-household savings estimate (1.9 and 4.7 thermostats per household for gas and electric, respectively) to a per-measure basis. Savings per household and per p-stat are shown in Table 4.

Table 4. Engineering-adjusted p-stat results by fuel type per p-stat

Measure Group	Savings per P-Stat	Savings per Household
Electric (kWh)	215	1,009
Gas (therms)	10.1	18.9

Conclusions

As a result of this study, programmable thermostats keep on rolling down the tracks, both for gas and electric programs. While the modest estimate for natural gas savings will force program managers to carefully consider cost-effectiveness in their program design when using them in gas-heated homes, savings are real and significant. Despite the caution given by the authors of various studies over the years, it appears that good old-fashioned programmable thermostats may be with us for some time to come, as long as programs are designed to ensure that p-stats are only installed as replacements for manual thermostats as part of a thoughtful program design.

For programs which implement a program design like that described for the EnergyWise program, for single family homes in weather zones similar to National Grid Rhode Island's territory, we recommend considering using the values found here for programmable thermostats in both electrically and gas heated homes, modified using Typical Meteorological Year heating degree days to fit the climate in question.

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