NAVIGANT

ComEd
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Research Report

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ComEd Advanced Thermostat Evaluation Research Report

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1. EXECUTIVE SUMMARY

This report presents the results of Navigant's impact evaluation research of advanced thermostats rebated by Commonwealth Edison (ComEd) in Program Year 8 (PY8).[1] Advanced thermostats are defined in section 5.3.16 of the Illinois Technical Reference Manual (IL TRM) version 6.0.[2] This study is intended to provide an estimate of annual electric cooling savings from advanced thermostats installed through energy efficiency programs in Illinois to support data-driven IL TRM updates. However, the IL TRM administrator and Technical Advisory Committee (TAC) are responsible for updating the IL TRM. Thus, this research is offered for consideration by those groups and does not represent explicit updates for the IL TRM.

This analysis focused on electric savings related to energy used for cooling and did not study other potential benefits of the technology such as leveraging advanced thermostats for customer engagement opportunities or the role of advanced thermostats in demand response programs. Navigant is currently conducting separate research in IL examining potential benefits of thermostat optimization programs[3] and general research around non-energy impacts.[4]

Navigant's evaluation research indicates that advanced thermostats rebated in PY8 in ComEd's service territory save:

- Less total annual electric energy than IL TRM v6.0 specifies
- About as much electric heating energy as IL TRM v6.0 specifies (primarily from furnace fans)
- Less electric cooling energy than IL TRM v6.0 specifies

As such, Navigant recommends that the VEIC and IL TRM TAC reference 2% cooling reduction as the finding from this study most applicable for informing any updates to the IL TRM.[5]

For future work, Navigant is preparing scope for a study that will leverage advanced metering infrastructure for advanced thermostat evaluation research using more recent participants. Navigant will coordinate with the Advanced Thermostat Subcommittee for that work.

Further detail on these findings and recommendations can be found in Section 6

2. INTRODUCTION

Navigant's evaluation research of advanced thermostats installed in the ComEd service territory during Program Year 8 (PY8) is a follow-up to Navigant's 2016 evaluation of ComEd's advanced thermostat pilot. In 2016, the technology was less mature and likely bought and installed by early adopters. Thus, the findings may have been unrepresentative of future program years. In this updated evaluation research, Navigant analyzed the savings achieved by advanced thermostats incentivized through the PY8 Home

[1] June 1, 2015 to May 31, 2016
[2] http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
[3] ComEd is currently running two thermostat optimization pilots with Nest and Whisker Labs.
[4] Navigant is currently conducting research for ComEd to update how non-energy impacts are quantified and included in cost effectiveness tests in IL.
[5] Navigant also shared other possible findings that could inform the IL TRM in its comments submitted to VEIC May 24, 2018.

Energy Assessment Program and Heating, Cooling, and Weatherization Rebate Program. This document summarizes the advanced thermostat measure's energy impacts; the methodology Navigant used to arrive at those figures; and sensitivity test results, which provide an indication of the findings' robustness and the limitations of the study.

The primary objective of this research was to update the "cooling reduction factor", defined in the Illinois Technical Reference Manual (IL TRM), which is used to calculate advanced thermostat annual electric savings. Navigant also provides information related to electric heating savings. Navigant did not estimate demand savings as a part of this study, nor did it investigate other possible benefits of advanced thermostats.

During this analysis, the EPA started certifying advanced thermostats under ENERGY STAR®.[6] This study did not include a rigorous investigation of their certification method.

3. Measure Description

As the IL TRM describes, an advanced thermostat reflects the "replacement of a manual-only or programmable thermostat, with one that has the default enabled capability —or the capability to automatically—establish a schedule of temperature setpoints according to driving device inputs above and beyond basic time and temperature data of conventional programmable thermostats."[7]

The IL TRM specifies this measure with heating and cooling reduction values (in units of savings per heating or cooling load) and customer specific heating and cooling load estimates, which vary based on home type, IL climate zone, heating system, AC efficiency, and participant characteristics. At a basic level, the product of the heating or cooling reduction and the heating or cooling load is measure savings. The IL TRM currently specifies two heating reduction values, one for replacing manual thermostats and one for replacing programmable thermostats. However, based on research[7], the IL TRM only specifies one cooling reduction value for advanced thermostats replacing either manual or programmable thermostats. Table 3-1 presents the IL TRM's heating and cooling percent reductions.

Table 3-1. IL TRM Heating and Cooling Percent Reductions for Advanced Thermostats

Weather Savings	Baseline Thermostat	Percent Reduction Value
Heating	Programmable	5.6%
Heating	Manual	8.8%
Cooling	Programmable or Manual	8%

Source: IL TRM v6.0

In Navigant's analysis, the participant set comprised 10,105 accounts who received an advanced thermostat rebate in PY8, after data processing and matching. Table 3-2 provides an overview of those accounts based on factors including home type, and proportion of homes that replaced programmable thermostats. For more information on site attrition, see Section B.2.

[6] https://nest.com/blog/2017/02/28/the-nest-thermostat-earns-an-energy-star/
[7] http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf

Table 3-2. Participant Overview

Participant Category	Participant Population PY8*	Analysis Dataset*	Subset of Analysis Dataset Unaffected by HER*
Number of Participants	23,944	10,105	2,641
Natural Gas Heat	96%	96%	96%
Central AC	99%	99%	99%
Programmable Thermostat Baseline	80%	84%	81%
Programmed Programmable Thermostat Baseline	44%	51%	50%
Single Family Homes	90%	93%	89%
Existing, rather than New, HVAC Systems	93%	94%	94%
Received One Rebate	95%	95%	95%
Nest Thermostat	80%	84%	85%
Ecobee Thermostat	20%	16%	15%
Received Home Energy Reports	57%	74%	0%

*The percentages represent the proportion of the dataset where the participant category could be consistently assigned based on program tracking data.
Source: ComEd billing and tracking data and Navigant team analysis.

4. Research Methodology

Navigant conducted this research by first developing an analytical method through stakeholder engagement, and then employing that approach to provide results the IL TRM administrator could use to support data-driven updates to the IL TRM.

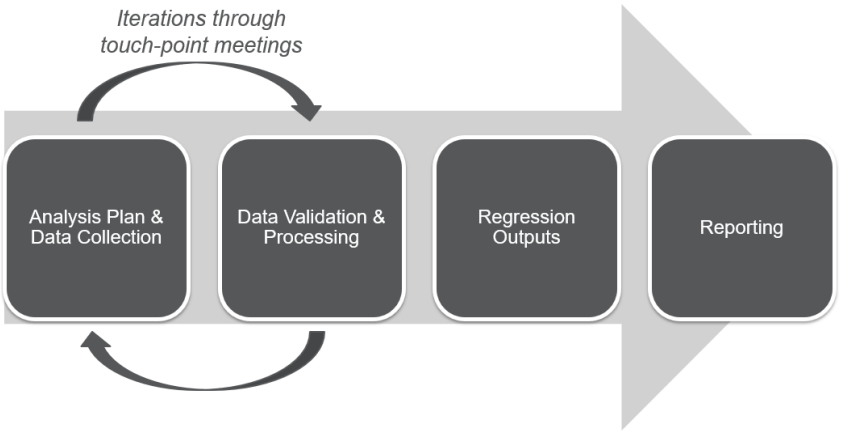
4.1 Methods Development

Navigant's preferred research approach is to develop an agreed-upon methodology before calculating results. Navigant considers this two-step process to be best practice in research, aligning with scientific principles. Additionally, this approach is intended to reduce the effects of confirmation bias and make work transparent and repeatable. Figure 4-1 presents a flow chart outlining the analysis' phases.

Navigant designed the advanced thermostat study to reach agreement on the methods prior to performing the analysis and providing results. This study involved coordination and communication with the Advanced Thermostat Subcommittee, a subcommittee within the IL TRM Technical Advisory Committee (TAC). Coordination primarily occurred throughout the planning, data collection, and methods development phases. Feedback not incorporated into the study was either identified for consideration in future research, or Navigant provided a response articulating our position on the issue. Please see Table A-1 for a detailed timeline of the evaluation research. See Section B.1 for examples of stakeholder feedback that Navigant incorporated into the study. The IL TRM administrator is responsible for

coordinating updates to the IL TRM in response to this research and Navigant will continue to include the IL TRM TAC Advanced Thermostat Subcommittee in any relevant future research.

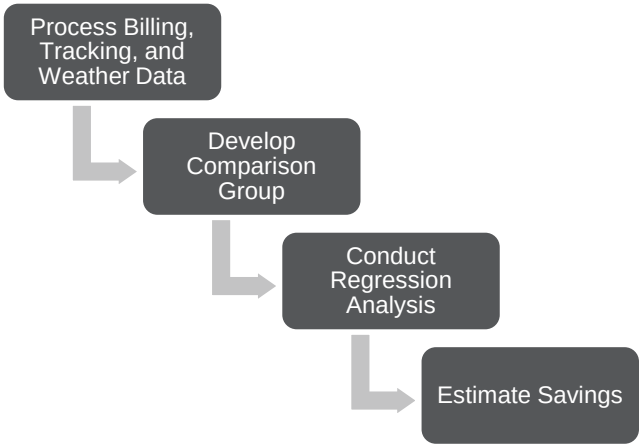
Figure 4-1. Evaluation Research Overview



4.2 Analysis Approach

The methodology for this study included four primary tasks, shown in **Error! Reference source not found.** Further details on each task can be found in Appendix B.

Figure 4-2. Advanced Thermostat Evaluation Research Task Overview



Navigant collected, processed, and validated the following datasets – customer billing, program tracking, and weather. Then, Navigant combined these datasets for analysis. Further details on processing tasks for each dataset can be found in Section 6.B.2.

Navigant developed the comparison group by finding, for each participant, the control account[8] with the most similar energy use during the matching period (June 2013 – May 2014), within the same zip code and Home Energy Report (HER) wave.[9] More details can be found in Section B.2.

Navigant estimated advanced thermostat savings using a Linear Fixed Effects Regression (LFER) model. This model compares energy use before and after treatment for customers who did and did not receive advanced thermostat rebates. This type of model was used in an Xcel Smart Thermostat evaluation, to evaluate smart thermostat savings in Michigan, and was recommended by subcommittee members during the methods development.[10] [11] [12] Section B.3 provides an overview of comparison group selection and a timeline of the pre-treatment, matching, and post-treatment periods; Sections B.4 and 6.B.5 provide further detail on the savings estimation methodology.

5. Advanced Thermostat Evaluation Research Results

Navigant provides results separately for (1) savings estimates, and (2) analysis outputs indicating the robustness and uncertainty of the results.

5.1 Savings Estimates

This study yielded results relevant to the IL TRM, the effect of HERs on advanced thermostat savings, and variation in savings for different baselines (e.g., programmable and manual thermostats).

5.1.1 *IL TRM*

For informing updates to the IL TRM, Table 5-1 compares savings estimated by Navigant's evaluation research for customers who did not receive HERs (see Section 5.1.2 for details) with savings calculated using the IL TRM v6.0. Navigant's evaluation research of advanced thermostats for PY8 participants in ComEd's service territory yielded a cooling reduction value of 2%. Because this type of analysis estimates net savings, no further net-to-gross (NTG) adjustment is necessary.[13] This analysis estimates cooling savings that are not statistically different than zero but are statistically different than the 8% defined in IL TRM v6.0 at the 90% confidence level. In addition to the cooling value, this study estimated a heating reduction value of 5.8%. The heating savings estimate is statistically different than zero and is in line with the values in the IL TRM. The total annual electric savings estimate (110 kWh per site per year) is statistically different than zero, and statistically different than the IL TRM's specified total savings for the PY8 participants.

[8] Control accounts did not receive an advanced thermostat incented by ComEd but may have installed an advanced thermostat on their own without obtaining a utility rebate. As such, Navigant considers the savings estimates from this study to be net savings.
[9] An HER wave refers to a group of customers who were enrolled in the HER program at the same time.
[10] Xcel Energy Evaluation: https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Regulatory%20Filings/CO-Smart-Thermostat-Pilot-Evaluation.PDF
[11] MI Evaluation Research: https://www.michigan.gov/documents/mpsc/Tier_3_Tstat_Calibration_Study_EWR_Presentation_623038_7.pdf
[12] Subcommittee members stated in their comments December 13, 2016, "For evaluating cooling and heating savings, the model should account for how weather affects energy use and how the thermostat affects this relationship. The CITS model accounts for these factors directly whereas the PO model does not, making CITS better suited for this analysis." Navigant's understanding is that the LFER model is comparable to CITS, which each differ from Navigant's preferred model – the post-only (PO) or lagged dependent variable model.
[13] The Illinois NTG Working Group is reviewing the relationship between billing analyses and net savings and Navigant will use those protocols for future studies once finalized.

Table 5-1. Advanced Thermostat Research Estimated and TRM Estimated Savings for Participants Not Receiving HERs

Savings Methodology	Sample Size	Cooling		Heating*		Total
		Percent Reduction (90% CI)	Electric Energy Savings by kWh/year/site	Percent Reduction (90% CI)	Electric Energy Savings by kWh/year/site	Electric Energy Savings by kWh/year/site (90% CI)
IL TRM v6.0	2,641	8%	170	6.2%†	96	266
Evaluation Research Findings	2,641	1.8% (-1.8 to 5.4%)	35	5.8% (1.5 to 10.2%)	74	110 (6 to 213)

*This evaluation focuses on electric savings, and the heating reduction corresponds in large part to furnace fan savings.
† Reflects a weighted average between the two IL TRM v6.0 heating reduction values for advanced thermostats replacing manual and programmable thermostats.
Source: ComEd billing and tracking data and Navigant team analysis.

5.1.2 *The Effect of HERs on Advanced Thermostat Savings*

ComEd's HER program affected 57% of ComEd residential advanced thermostat recipients in PY8. Additionally, three quarters of the customers included in the evaluation research data set after processing had received HERs.

The IL TRM should specify measure savings that are not diminished by HER, because HER program evaluations have a standard practice of removing savings attributed to other measures and programs, including advanced thermostats, through an "Uplift" analysis when reporting savings. This approach ensures that IL energy efficiency programs aren't double penalized for savings that overlap, and that savings aren't double counted. Navigant found 2% cooling savings for PY8 advanced thermostat participants who did not receive HERs and about 0, or even perhaps slightly negative cooling savings for participants who did receive HERs (see Table 5-2). Neither cooling savings estimate is statistically different than zero with 90% confidence, but each is statistically different than the IL TRM v6.0, which specifies 8% cooling reduction. Additionally, the cooling savings between HER and non-HER groups aren't statistically significantly different with 90% confidence, but the trend is consistent across sensitivity testing and is statistically significantly different with 70% confidence.

Table 5-2. Advanced Thermostat Research Estimated Savings by HER Status

Participant Group	Sample Size	Cooling		Heating*		Total
		Percent Reduction (90% CI)	Electric Energy Savings by kWh/year /site	Percent Reduction (90% CI)	Electric Energy Savings by kWh/year /site	Electric Energy Savings by kWh/year /site
All PY8 Advanced Thermostat Participants with Adequate Data	10,105	-0.3%	-7	6.4%	88	81
PY8 Participants Receiving Home Energy Reports (HERs)	7,464	-0.9% (-2.8 to 0.9%)	-21	6.5% (4.3 to 8.7%)	93	72
PY8 Participants Not Receiving Home Energy Reports (HERs) – useful to Inform the IL TRM	2,641	1.8% (-1.8 to 5.4%)	35	5.8% (1.5 to 10.2%)	74	110

*This evaluation focuses on electric savings, and the heating reduction corresponds in large part to furnace fan savings.
Source: ComEd billing and tracking data and Navigant team analysis.

The participant group labeled as "All PY8 Advanced Thermostat Participants with Adequate Data" in Table 5-2 will be referred to as the "PY8 participant group," hereafter. The "PY8 Participants Not Receiving Home Energy Reports (HERs) – useful to Inform the IL TRM" participant group is a subset of the PY8 participant group and will be referred to as the "TRM-recommended participant group (excludes HER effects)," hereafter. The TRM-recommended participant group (excludes HER effects) was formed by filtering the "PY8 participant group" to only customers that did not participate in the HER program.

5.1.3 *Different Baseline Thermostats*

Navigant compared savings from advanced thermostats replacing different baseline thermostats. The IL TRM defines a single value for cooling reduction (8%) for advanced thermostats replacing manual or programmable thermostats. However, the TRM defines two heating savings values, one for a manual thermostat baseline (8.8%) and one for a programmable thermostat baseline (5.6%) replaced by an advanced thermostat. Navigant found consistent cooling savings regardless of whether participants replaced manual or programmed programmable thermostats but found much higher heating savings for participants who replaced manual thermostats compared to programmed programmable thermostats (see Table 5-3). These results have high uncertainty and variance, but don't indicate a need at this time for revising the IL TRM's framework of specifying two heating reduction values and only one cooling reduction value. This topic could be revisited in future work.

Table 5-3. Advanced Thermostat Research Estimated Savings by Baseline Thermostat

Participant Group	Sample Size	Cooling		Heating*	Total	
		Percent Reduction	Electric Energy Savings by kWh/year/site	Percent Reduction	Electric Energy Savings by kWh/year/site	Electric Energy Savings by kWh/year/site (90% CI)
All Sites*	10,105	-0.3%	-7	6.4%	88	81 (29 to 134)
Manual Thermostat Baseline	1,550	-0.7%	-16	10.7%	155	139 (7 to 271)
Programmed Programmable Thermostat Baseline	4,883	-0.5%	-11	4.9%	68	58 (-20 to 135)

*The results for manual baseline thermostats and programmed programmable thermostat baselines do not average to "all sites," because there are additional groups for which we have not isolated savings (e.g., programmable thermostats on hold and where this data is unknown).

Source: ComEd billing and tracking data and Navigant team analysis.

5.2 Robustness and Uncertainty of the Results

In this subsection, Navigant speaks to the limitations of this study and to our best effort to provide additional analysis outputs that can inform our interpretation of the findings given these limitations.

1. **Statistical Significance:** Navigant presents some savings estimates that are not significantly different than zero but are significantly different than the values in IL TRM v6.0 at the 90% confidence level. This level of uncertainty is not ideal but does provide an indication that updates to the IL TRM are warranted.
2. **Self-Selection Bias:** Self-selection bias affects all regression-based approaches to estimating savings that do not include a randomized or experimental study design. This study did not employ a randomized design but used industry best-practices for non-experimental design approaches. In order to determine if self-selection was an issue, Navigant ran sensitivity analyses comparing participant and control usage for the two years prior to the treatment period and found no signs that the two groups were diverging. This result indicates self-selection bias did not strongly affect energy use prior to program participation (see Appendix D for more details). Furthermore, Navigant also developed multiple comparison groups, which provide an indication as to the sensitivity of the results to a single comparison group; Navigant found that these groups yielded consistent savings estimates. Navigant presents more details on the sensitivity analysis in Section C.1. While these additional analysis outputs don't prove the absence of self-selection, they do serve as additional rigor beyond standard practice, and show no signs of self-selection bias. These results indicate that if self-selection bias is affecting results, the effect would have to be equal across the various comparison groups and the effect would have to start occurring simultaneously with the program, having not been occurring prior.
3. **Past and Future Savings:** Evaluation research typically provides accurate estimates of savings retrospectively, which can inform energy efficiency program planning, but are imperfect predictors of the future. This challenge is not unique to advanced thermostats. This study is intended to provide an independent estimate of PY8 advanced thermostat electric savings to support data-driven IL TRM updates. The IL TRM administrator and the IL TRM TAC are responsible for IL TRM updates, and can use this information to make informed updates.

4. **Model Specification:** Model specification bias refers to possible erroneous results due to model misspecification. Matching to a comparison group is designed to limit model specification bias by making the comparison group as similar to the participants as possible based on observable characteristics. To investigate remaining model specification bias after matching in this study, Navigant tested seven total model specifications, which all yielded consistent findings. Navigant presents these sensitivity results in SectionAppendix C. These findings indicate that any possible imperfections in the model specification appear to have a limited effect on the savings estimate.

6. Evaluation Research Findings and Recommendations

The following describes key evaluation research findings and recommendations.

Finding 1. Electric cooling and total annual electric energy savings attributed to advanced thermostats are statistically different than what is defined in the IL TRM v6.0 at the 90% confidence level. Electric heating savings are not statistically different from the value in the IL TRM at the 90% confidence level.

Recommendation 1. Navigant recommends the IL TRM administrator and the IL TRM TAC consider updating the cooling reduction factor in the IL TRM v7.0. They can reference 2% cooling reduction as the finding from this study most applicable for informing any updates to the IL TRM.

Finding 2. Navigant found an indication that advanced thermostat participants who had been receiving Home Energy Reports saved less cooling energy than advanced thermostat participants who had not been receiving the reports, although this trend was not statistically significant at the 90% confidence level.

Finding 3. While not statistically significant with 90% confidence, homes that replaced manual thermostats with advanced thermostats tended to have equivalent cooling savings, but higher heating savings, compared to homes that replaced programmed programmable thermostats with advanced thermostats. This finding aligns with the IL TRM v6.0, which specifies two heating reduction values (one for manual thermostat baselines and one for programmable thermostat baselines), but only one cooling reduction value. These results have high uncertainty and variance, but don't indicate a need for revising the IL TRM's framework of specifying two heating reduction values and only one cooling reduction value. This topic could be revisited in future work.

APPENDIX A. EVALUATION RESEARCH TIMELINE

As shown by the dates in Table A-1. Evaluation Research Timeline

, this project progressed from initial proposed methods to publicly available regression results over about 22 months. During this time, the Advanced Thermostat Subcommittee used seven months to reach consensus on methods, data collection required 10 months due to the magnitude of the data, and Navigant used five months to conduct the analysis and deliver and discuss regression outputs with the subcommittee. For future projects involving engaged stakeholders and complex analysis, evaluators may consider more expeditious processes, such as requesting data before reaching agreement on methods. This approach would enable discussions on methods and data collection to happen in parallel but would limit stakeholders' ability to comment on the data request.

Table A-1. Evaluation Research Timeline

Date	Evaluation Event
June 17, 2016	Navigant shared the first draft of our detailed research plan with stakeholders.
By January 20, 2017	The subcommittee finalized the high-level evaluation methodology and data needs during a touch-point meeting and through e-mail.
February 2, 2017	Navigant requested energy use data from ComEd.
March 4, 2017	VEIC shared with the subcommittee that Navigant was not able to obtain thermostat data from manufacturers due to substantial and unanticipated challenges.
November 7, 2017	The subcommittee finalized the methodology for calculating usage reduction percentage (% reduction) from the regression outputs during a touch-point meeting.
December 18, 2017	Navigant received final evaluation data from ComEd.
December 19, 2017	Navigant validated evaluation data and confirmed data sufficiency.
February 7, 2018	The subcommittee validated comparison group matches through e-mail.
April 25, 2018	Navigant delivered regression outputs.
May 7 to June 19, 2018	The subcommittee discussed regression outputs, future research tasks and implication to the IL TRM version 7 during two touch-point meetings and a comment-and-response period.
August 27, 2018	Navigant delivered the draft report

Source: ComEd billing and tracking data and Navigant team analysis.

APPENDIX B. EVALUATION RESEARCH METHODOLOGY

This appendix provides detail on each of the primary tasks completed during the evaluation research as well as stakeholders' influence on methods.

B.1 Stakeholder Influence on Methods

This appendix subsection provides detail on the stakeholder engagement process for this study. Due to stakeholder feedback, Navigant adjusted the proposed methods and conducted additional robustness and sensitivity tests (see bulleted lists below). However, some comments, such as suggestions to use AMI data, could not be incorporated due to various constraints. For example, AMI was only available for 18% of ComEd's total meters in 2014, which would have affected evaluation of PY8 participants. Conducting this analysis with AMI would have reduced the sample size to a point where the new data stream would add uncertainty rather than reduce it.[14] Examples of Navigant's adjustments to the methods include the following:

- **Model Type:** Navigant compromised with one thermostat manufacturer to use a model specification aligned with their preferences. Navigant used a linear fixed effect regression (LFER) model in this analysis. Navigant initially proposed a post-only, or lagged dependent variable, model, where the manufacturer expressed preference for a LFER or comparative interrupted time series (CITS) model, as exemplified in the following quote: "For evaluating cooling and heating savings, the model should account for how weather affects energy use and how the thermostat affects this relationship. The CITS model accounts for these factors directly whereas the PO model does not, making CITS better suited for this analysis." – A Thermostat Manufacturer, December 13, 2016.
- **Specific Model Parameters:** Navigant compromised with a thermostat manufacturer on specific model parameters. Navigant originally proposed a model that produced savings only as those correlated with heating (i.e., post*treat*HDD) and those correlated with cooling (i.e., post*treat*CDD), but the thermostat manufacturer requested a "main treatment effect" (i.e., post*treat), which Navigant was willing to include in the model.[15]
- **Matching by Zip:** Navigant compromised with a thermostat manufacturer and the Environmental Law and Policy Center (ELPC) to restrict the comparison group matching to be within zip code. Navigant feels that if matching by zip code has a strong impact on energy use, matching on pre-installation energy use alone will inherently account for any benefits from this additional restriction. For example, ELPC stated in their comments December 13, 2016 "ELPC believes matches should be made with a higher level of geographic granularity, ideally matching within the same zip code."

[14] Navigant proposed to use AMI as of November 18, 2016, but agreed with a manufacturer's comments from December 13, 2016, which stated "We support using AMI data rather than monthly billing data but are also concerned with sample attrition and representativeness. What fraction of rebate participants will have a full year of pre-installation daily AMI data. If there is large attrition, then we have concerns about potential bias." Using AMI to evaluate PY8 participants could have reduced the sample size by almost 80% and the subcommittee agreed to use billing data at the touch-point meeting January 20, 2017.

[15] A manufacturer commented on December 13, 2016 "the proposed regression model (Equation 1) estimates savings only through an interaction term with cooling degree days (CDD70) and does not include any main treatment effect" and the subcommittee agreed on January 20, 2017 during the touch-point meeting to include this additional variable in the model.

- **Balance Temperatures:** At the request of the ICC staff, Navigant changed the balance temperatures used to calculate heating and cooling degree-days to reflect the IL TRM (60° for heating and 65° for cooling).

After presenting initial results, Navigant also conducted additional analysis and provided additional content as requested by the subcommittee. Examples of these additional items are included in the following:

- **ICC Staff Requests:** Navigant conducted analyses requested by the ICC staff on May 9, 2018. These analyses included additional investigation for signs of possible self-selection bias as well as unique estimates of savings for subsets of the population. The results of these analyses are presented in Navigant's second addendum shared May 22, 2018, which is also available on the TRM SharePoint.[16] These results are also included in Appendix D.
- **Thermostat Manufacturer Requests:** As requested by one thermostat manufacturer, Navigant provided monthly energy use and weather data to the subcommittee on May 24, 2018.

B.2 Process Billing, Tracking and Weather Data

The following subsections outline the steps taken to process each data source.

B.2.1 Billing Data

Prior to billing data processing, the dataset included 23,884 participants and 1,946,260 controls. The billing data was then processed by developing a dataset with unique observations by read date and account number. Billing data processing primarily involved removing duplicate records and accounts with insufficient data. Navigant also confirmed that the processed data aligned with data used in other evaluations where overlap existed.

[16] Navigant's presented slides and subsequent addendum can be found at the following link and are titled "ComEd - Adv Therm - Regr Outputs - DRAFT - 2018-04_25," "ComEd - Adv Therm - Regr Outputs Addendum - DRAFT - 2018-05-08," and "ComEd - Adv Therm - Regr Outputs Addendum2 - DRAFT - 2018-05-22" - https://portal.veic.org/projects/illinoistrm/Shared%20Documents/Forms/AllItems.aspx?RootFolder=%2fprojects%2fillinoistrm%2fShared%20Documents%2fWorking%20Group%20Materials%2fAdvanced%20Thermostat%20Subcommittee%2fComments%20to%20Navigant%27s%20Report%20and%20or%20Next%20Steps%20for%20TRM%20Update%20May%2029%202018&FolderCTID=0x01200042B0ABF3AA22EE4888A0EDE62AB5CED4

Table B-1. Site Attrition Due to Data Processing

Data Processing Step	Participants	Controls
Raw Data	23,884	1,946,260
Bad Reads (e.g., All Estimated Bills)	23,884	1,946,259
Averaged Bills in the Same Month	23,884	1,946,259
Removed Outliers (i.e., observations one order of magnitude above or below median usage)	23,884	1,946,234
Had 10+ Observations in Pre- and Post-Periods	13,303	1,331,410
Received No Other Rebates or Rebated Measures from Res HVAC or HEA Programs	11,571	1,281,579
Had Matches in same HER Wave and Zip	10,554	1,281,579
Had 10+ Observations in the Matching Period	10,105	1,239,002
Match Participants and Controls to Form Analysis Dataset	10,105	9,407

Source: ComEd billing and tracking data and Navigant team analysis.

B.2.2 Tracking Data

Tracking data from several program years of the Home Energy Assessment and Heating, Cooling and Weatherization Rebate programs was used to identify customers that received rebates for advanced thermostats as well as for other measures. Navigant removed accounts from the combined dataset (i.e., for participants and the comparison group) that received rebates for other measures, and for advanced thermostats in years other than PY8, so that measure-related energy impacts could be attributed solely to PY8 advanced thermostats.

B.2.3 Weather Data

To provide savings estimates for both an actual and a typical meteorological year, Navigant used actual weather data from the National Oceanic and Atmospheric Administration (NOAA) and typical weather data from Typical Meteorological Year (TMY3) datasets. The results presented in Section 5 reflect typical year savings. Data processing for weather data consisted of developing heating and cooling degree-days, which were used as terms in the regression model as well as to estimate annual savings. These weather data sources and associated processing steps are described in further detail in the following subsections.

Actual Weather Data
Navigant used actual weather (drybulb) values in the advanced thermostat regression model. Weather values came from NOAA quality controlled local climatological data weather stations. We used weather data from the closest weather station relative to the account's zip code centroid.[17, 18]

Navigant calculated Heating and Cooling Degree Days (HDD and CDD) hourly with balance temperatures of 60 and 65 respectively. For example, if a weather station had an hourly temperature of 55, it would have a Heating Degree Hour (HDH) value of 5 for that hour. These hourly HDH and CDH values were then summed up for each day, and divided by 24 to get daily HDD and CDD values. Navigant then summed up daily HDD and CDD values over each month, and divided that figure by the number of days in that month to approximate average monthly HDD and CDD per day. We combined weather and usage

[17] Because participants and controls were matched on zip code, both matched accounts had the same weather data for the analysis.
[18] In instances where a station was missing data, we filled those values with weather from O'Hare International Airport.

data by year and calendar month. Navigant also combined these data by read date in some of its sensitivity testing of the results.

Typical Meteorological Year Data

Navigant used TMY3 data to estimate program savings for a typical weather year. This data provides hourly meteorological values that typify weather for a specific location and calendar month.[19] TMY3 values allow Navigant to estimate energy savings in absolute values for typical weather years. Navigant calculated average annual HDD and CDD values based on monthly figures using the method described in the previous subsection. Navigant multiplied TMY HDD and CDD values by the treatment effect coefficients, which incorporated weather values, as described in Section B.4.

B.3 Develop Comparison Group

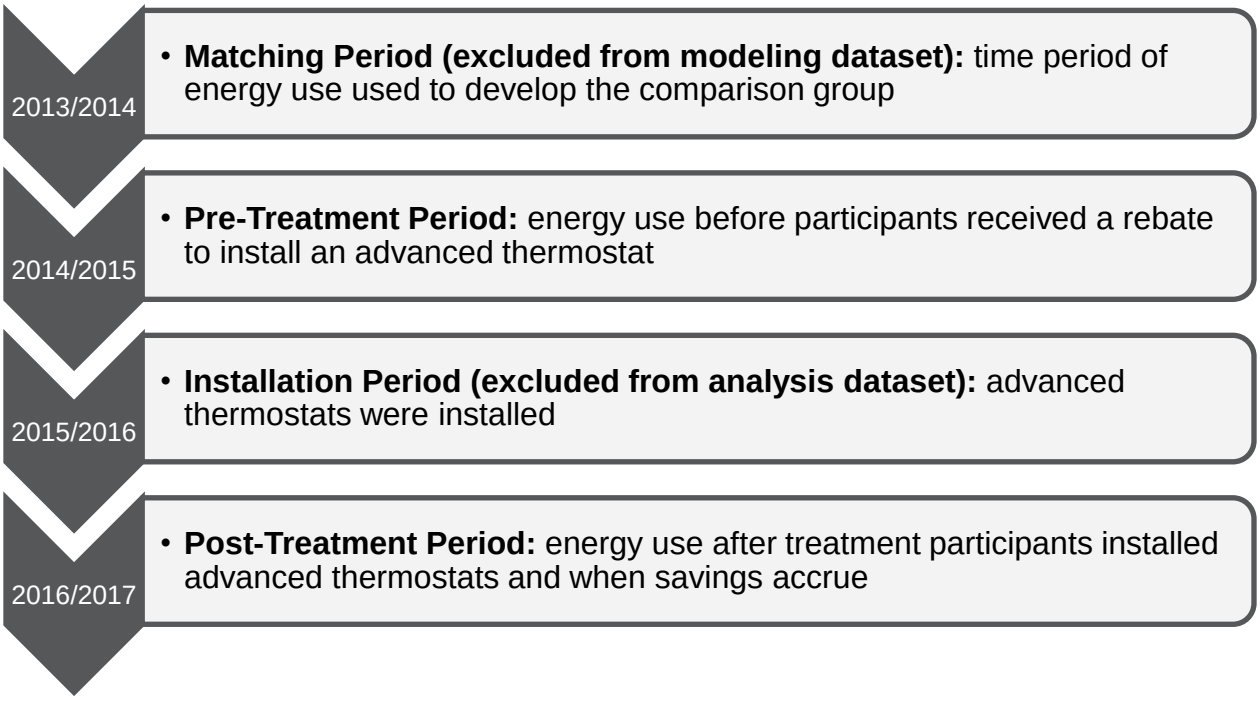
Navigant developed a comparison group by matching participant usage (customers with advanced thermostats) to a pool of potential controls (customers without advanced thermostat rebates) based on similar energy usage. The pool of non-participant households available for matching consisted of approximately two million ComEd residential customers.[20] Navigant matched participants to controls within the same zip code and HER wave to control for additional factors which could influence energy savings. The purpose of this matching method was to develop a comparison group that best reflects the participant group based on the differences in energy use between a participant and control in the period before the participant upgraded their thermostat.[21] Navigant refers to the period before the participant upgraded their thermostat, when energy consumption data was used to develop the comparison group, as the "matching period." Figure B-1 provides an overview of the four discrete time periods relevant to the analysis.

[19] Wilcox, S and W. Marion, 2008. *Users Manual for TMY3 Data Sets*. NREL/TP581-43156.

[20] This number includes accounts that did and did not receive HER.

[21] The quality of a match is denoted by the Euclidean distance to the participant. This distance is measured as the mean squared of the difference in monthly energy use between a participant and a potential match in terms of pre-usage over the matching period. The non-participant customer with the shortest Euclidean distance to a participant is chosen as the matched comparison for the participant. Matching, for this study, was done with replacement and the standard error accounted for this by using a robust standard error that clustered the error around the individual at every instance of each individual.

Figure B-1. Advanced Thermostat Evaluation Research Time Periods



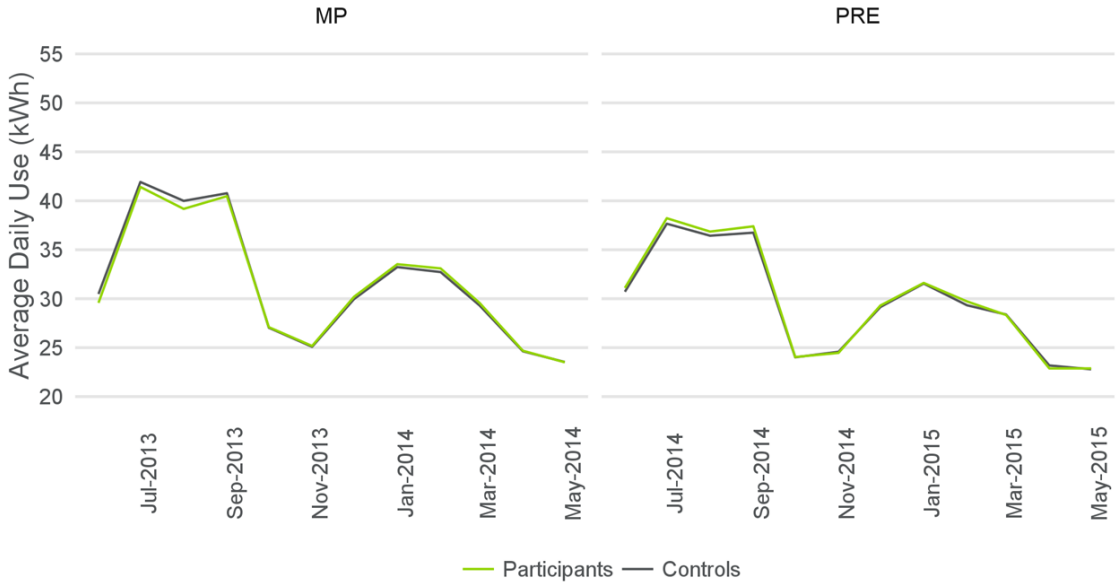
Navigant validated the matched comparison group by visualizing average monthly usage for participants and controls during the matching period. Navigant compared usage during the pre-treatment period as a secondary test of goodness-of-fit. Figure B-2 shows the of average monthly usage for participants and controls in the matching and pre-treatment periods for the PY8 participant group. Since the matching method did not include usage during pre-treatment months (June 2014 – May 2015), similar participant and control usage in that period would suggest the matches are performing well. Navigant's selection of matches used for regression was supported by participant and control usage being approximately the same during *both* the matching *and* pre-treatment periods. Furthermore, this approach is consistent with the academic literature.[22,23,24] Navigant also conducted additional analysis to determine that groups used energy similarly before advanced thermostats were rebated and found similar savings estimates across multiple comparison groups. Plots of the matched comparison groups used in these sensitivity analyses are in section C.1.

[22] Stuart, E.A. and Rubin, D.B. 2007. Best Practices in Quasi-Experimental Designs: Matching methods for causal inference. Chapter 11 (pp. 155-176) in *Best Practices in Quantitative Social Science*. J. Osborne (Ed.). Thousand Oaks, CA: Sage Publications. (GS citations: 131)

[23] Ho, D.E., K. Imai, G. King, and E.Stuart. 2007. Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political Analysis* 15(3): 199-236. (GS citations: 1590). Winner of Warren Miller Prize for best paper published in *Political Analysis* in 2007

[24] Imbens, G.M. and J.M Wooldridge.2008. "Recent developments in the econometrics of program evaluation". National Bureau of Economic Research, working paper no. 14251. http://www.nber.org/papers/w14251. (GS citations: 2029).

Figure B-2 PY8 Participant Group Matching Plot



Source: ComEd billing and tracking data and Navigant team analysis.

B.4 Conduct Regression Analysis

To estimate energy savings, Navigant used a Linear Fixed Effects Regression (LFER) model. In this model, average daily kWh consumption by household *k* in bill period *t* is denoted by $ADU_{k,t}$. Formally, the expression of the LFER model is shown in Equation 1.

Equation 1. Linear Fixed Effects Regression Model

$$ADU_{k,t} = \alpha_k + \beta_1 HDD_{60,k,t} + \beta_2 CDD_{65,k,t} + \beta_3 post_t + \beta_4 post_t * HDD_{60,k,t} + \beta_5 post_t * CDD_{65,k,t} + \beta_6 treat_k * HDD_{60,k,t} + \beta_7 treat_k * CDD_{65,k,t} + \beta_8 post_t * treat_k + \beta_9 post_t * treat_k * HDD_{60,k,t} + \beta_{10} post_t * treat_k * CDD_{65,k,t} + \varepsilon_{k,t}$$

Where:

α_k = Site fixed effects, which are binary variables (one for each site) that take on the value of 1 for a given site, *k,* and 0 otherwise. This variable accounts for site specific conditions that do not change over time, such as the number of occupants.

$HDD_{60,k,t}$ = Heating degree days for customer k during time (i.e., bill) *t* at a 60ºF balance temperature.

$CDD_{65,k,t}$ = Cooling degree days for customer k during time (i.e., bill) *t* at a 65ºF balance temperature.

$post_t$ = A binary variable indicating whether time period *t* is after the advanced thermostat installation (taking a value of 1) or before (taking a value of 0). This variable will take values of 1 and 0 for both participant and comparison group sites.

$treat_k$ = A binary variable indicating whether customer *k* is in the treated participant group (taking a value of 1) or in the comparison group (taking a value of 0). This variable will not change over time for any customers.

$\varepsilon_{k,t}$ = The cluster-robust error term for customer *k* during time period *t*. Cluster-robust errors account for heteroscedasticity and autocorrelation at the customer level.

Three observations about this specification deserve comment. First, the coefficient α_k captures all household-specific effects on energy use that do not change over time, including those that are unobservable. The effect of being both in the treatment group and in the post-period (i.e., the effect directly attributable to the program), is captured by the coefficients β_8, β_9 and β_{10}. The model interacts account participation in the treatment group during the post-period with weather through coefficients β_9 and β_{10}.

B.5 Estimate Savings

Navigant's model allowed for the calculation of savings to be represented as total savings, using Average Treatment Effects (ATE), and heating and cooling reduction, in units of savings per heating or cooling load. These representations are described in the following subsections.

B.5.1 Estimating Savings – Average Treatment Effect

Navigant estimated total savings using TMY3 data and ATE, representing energy savings in absolute values for typical weather years. To estimate the savings, Navigant calculated average treatment effects for variables that included participant usage during the post-period. To calculate annualized ATE, Navigant multiplied coefficient estimates for β_8, β_9, and β_{10} by the annualized mean value associated with those variables.[25] For example, coefficient β_9 had a mean HDD per year value of 4,964, which resulted in an annual ATE of -132, or a 132 kWh reduction in average annual usage relative to controls after correcting for weather. Table B-2 presents an overview of these calculations.

Table B-2. Calculating Annualized Average Treatment Effect

Coefficient	Treatment Effect Model Term	Estimate	Mean Value	ATE (kWh/year)
β_8	Savings per Day	0.31 (kWh/day)	365 (days/year)	114
β_9	Savings per HDD	-0.03 (kWh/HDD)	4,964 (HDD/year)	-132
β_{10}	Savings per CDD	-0.07 (kWh/CDD)	927 (CDD/year)	-63

Source: ComEd billing and tracking data and Navigant team analysis.

Summing the ATE values in Table B-2 results in a combined annual ATE of -81 kWh, or an 81 kWh reduction in average annual usage relative to controls after correcting for weather. This ATE value corresponds to the annual savings of 81 kWh as shown in the entry for "All PY8 Advanced Thermostat

[25] Weather coefficients used average monthly HDD and CDD values calculated with TMY3 data.

Participants with Adequate Data" in Table 5-2. Advanced Thermostat Research Estimated Savings by HER Status

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B.5.2 Estimating Savings – Heating and Cooling Percentage Reductions

Navigant also represented savings as percentage reductions in energy used for heating and cooling. The model provides savings per day, per HDD, and per CDD. Savings per HDD represent savings associated with energy used for heating while savings per CDD represent savings associated with energy used for cooling. As agreed to during the November 2017 touchpoint meeting, baseline heating and cooling loads were used to break out "per day" savings into per-HDD and per-CDD savings. To calculate the reduction percentages, annual savings were divided by the respective heating and cooling loads to find percentage reductions in energy used for heating and cooling.

APPENDIX C. SENSITIVITY ANALYSES

This appendix contains results of the sensitivity analyses Navigant conducted. Navigant tested the sensitivity of the results estimated with the PY8 participant group to various comparison test groups, model specifications, and alternate data processing approaches.

C.1 Sensitivity to Different Matched Comparison Groups

Navigant conducted sensitivity analyses using different matched comparison groups to provide an indication of the sensitivity of the results to any one matched comparison group. Table C-1 compares the matching and observations requirements for the PY8 participant group with those of three comparison test groups[26].

Table C-1. Overview of Matching and Observations Requirements in Sensitivity Tests

Matched Comparison Group	Sample Size - Treatment	Sample Size - Control	Matching Method	Observation Requirements	Calipers Used to Filter Bad Matches
PY8 Participant Group	10,105	9,407	Sum of squared difference	Participants had 10 or more observations in all periods. Controls had 8 or more observations in all periods.	No
Comparison Test Group 1	8,193	8,193	Sum of absolute value of difference	10 months in all periods.	Yes
Comparison Test Group 2	10,451	9,974	Sum of absolute value of difference	10 or more observations during matching. 8 or more observations in pre- and post-periods	No
Comparison Test Group 3	10,105	9,661	Average squared difference	10 or more observations in all periods	No

Source: ComEd billing and tracking data and Navigant team analysis.

As shown in Table C-2, results from each of the comparison test groups are statistically similar to the PY8 participant group results. Furthermore, the PY8 participant group and each of the comparison test groups yielded savings estimates consistently lower than the values defined in the IL TRM. Navigant continued to make data improvements up until April 25, 2018, when the PY8 participant group was formed, and provides additional results from the comparison test groups as a robustness check on the findings. These robustness checks indicate that the findings are stable and are not dependent on a single comparison group.

[26] These groups correspond to the matched comparison groups named by date that were presented to evaluation research stakeholders. Comparison test groups 1 through 3 correspond to the 2018-02-06, 2018-04-03, and 2018-05-01 matched comparison groups

Table C-2. Sensitivity Analysis Results Using Different Matching and Observation Thresholds

Matched Comparison Group	Cooling		Heating		Total
	Percent Reduction (90% CI)	Electric Energy Savings by kWh/year/site	Percent Reduction (90% CI)	Electric Energy Savings by kWh/year/site	Electric Energy Savings by kWh/year/site (90% CI)
PY8 Participant Group	-0.3% (-2.0 to 1.4%)	-7	6.4% (4.4 to 8.4%)	88	81 (29 to 134)
Comparison Test Group 1	0.9% (-1.1 to 2.9%)	20	9.1% (6.7 to 11.4%)	116	136 (75 to 196)
Comparison Test Group 2	-1.7% (-3.2 to -0.3%)	-38	5.7% (3.8 to 7.6%)	79	41 (-12 to 94)
Comparison Test Group 3	-1.9% (-3.5 to -0.2%)	-41	5.7% (3.8 to 7.7%)	79	39 (-13 to 90)

Source: ComEd billing and tracking data and Navigant team analysis.

In Sections C.1.1 through **Error! Reference source not found.**, Navigant provides additional information associated with the results of each comparison test group sensitivity analysis as well as the same information for the PY8 participant group for reference. For both the PY8 participant group and the comparison test groups, Navigant provides the regression model output, plots of average monthly usage for participants and controls in the matching and pre-treatment periods, and the numerical values used to create the plots.

C.1.1 PY8 Participant Group

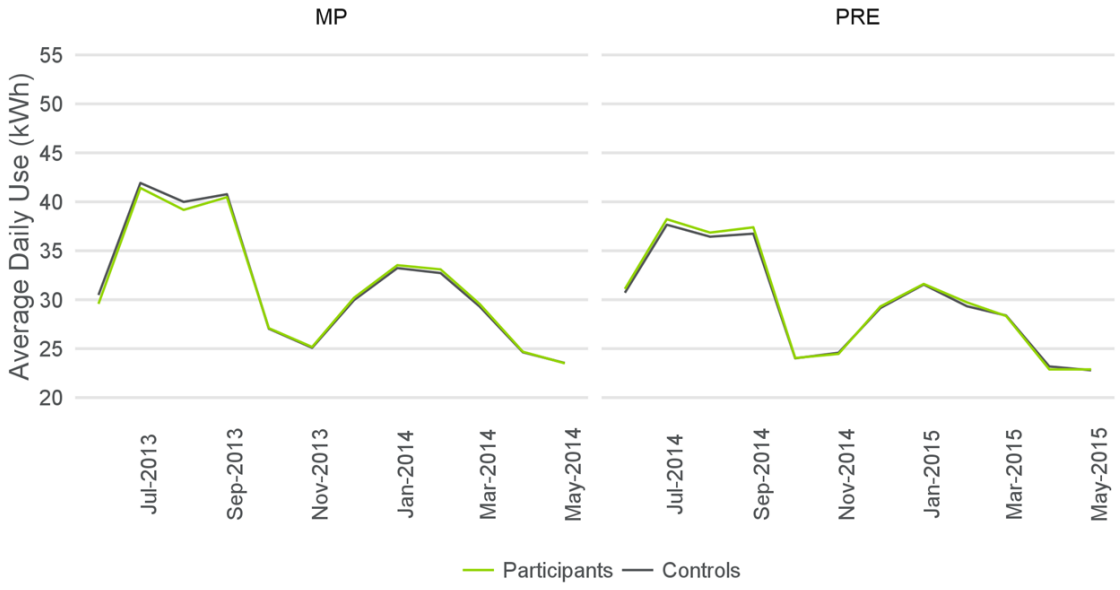
The PY8 participant group used data from participants that had 10 months of data in each period and controls that had eight or more months of data in each period. Participants and controls were matched using the sum of squared difference in energy usage.

Table C-3. Regression Output – PY8 Participant Group

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.18	0.004	<0.01	911
CDD	1.64	0.017	<0.01	1,525
Post	-3.41	0.085	<0.01	-1,243
HDD*Post	0.09	0.003	<0.01	434
CDD*Post	0.62	0.014	<0.01	570
HDD*Treat	0.01	0.005	0.18	35
CDD*Treat	0.09	0.024	<0.01	80
Post*Treat	0.31	0.122	0.01	114
HDD*Post*Treat	-0.03	0.005	<0.01	-132
CDD*Post*Treat	-0.07	0.019	<0.01	-63

Source: ComEd billing and tracking data and Navigant team analysis.

Figure C-1. Matching Plot – PY8 Participant Group



Source: ComEd billing and tracking data and Navigant team analysis.

Table C-4. Matching Plot Data – PY8 Participant Group

Month	MP – 2013/2014 (kWh / day / site)			Pre-Period – 2014/205 (kWh / day / site)		
	Participants	Comparison	Difference	Participants	Comparison	Difference
6	29.58	30.48	-0.90	31.10	30.71	0.39
7	41.41	41.92	-0.51	38.22	37.66	0.56
8	39.17	39.99	-0.82	36.85	36.43	0.42
9	40.47	40.77	-0.30	37.39	36.74	0.65
10	27.09	27.04	0.06	24.04	24.02	0.03
11	25.17	25.09	0.08	24.47	24.58	-0.11
12	30.20	29.96	0.24	29.31	29.15	0.16
1	33.52	33.23	0.30	31.61	31.55	0.06
2	33.09	32.72	0.37	29.72	29.33	0.39
3	29.56	29.30	0.26	28.34	28.39	-0.05
4	24.68	24.63	0.06	22.88	23.18	-0.30
5	23.50	23.53	-0.03	22.88	22.79	0.09

Source: ComEd billing and tracking data and Navigant team analysis.

C.1.2 Comparison Test Group 1

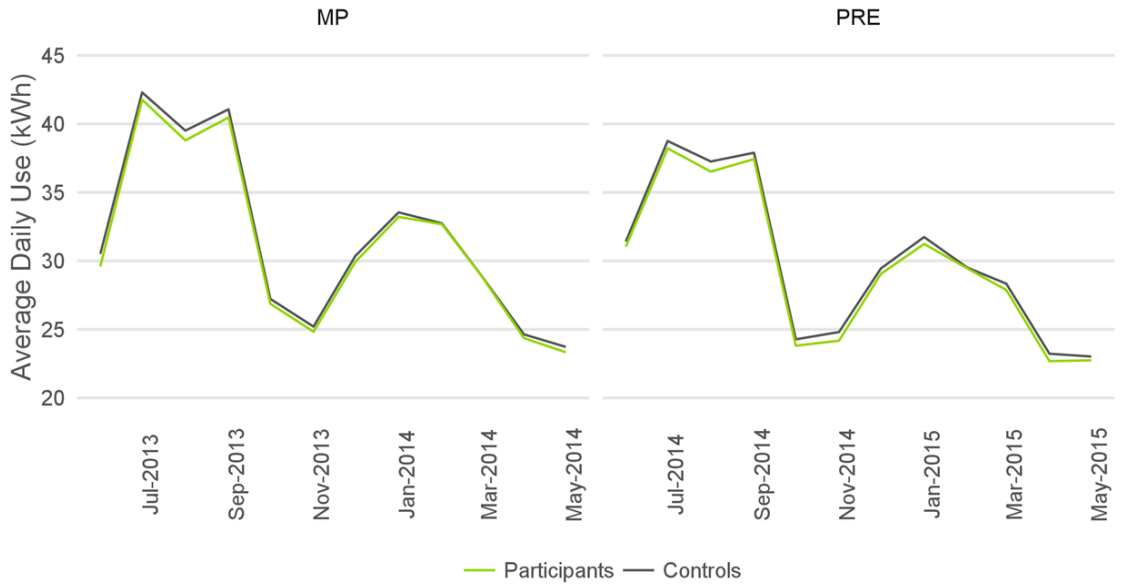
Comparison test group 1 used data from participants and controls that had 10 months of data in each period and were matched using the sum of absolute value of difference in usage.

Table C-5. Sensitivity Analysis Regression Output – Comparison Test Group 1

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.18	0.004	<0.01	902
CDD	1.74	0.018	<0.01	1,614
Post*	-3.07	0.097	<0.01	-1,121
HDD*Post	0.07	0.004	<0.01	372
CDD*Post	0.60	0.015	<0.01	555
HDD*Treat	0.00	0.005	0.71	10
CDD*Treat	-0.01	0.025	0.73	-8
Post*Treat	0.23	0.134	0.09	83
HDD*Post*Treat	-0.03	0.005	<0.01	-147
CDD*Post*Treat	-0.08	0.020	<0.01	-71

Source: ComEd billing and tracking data and Navigant team analysis.

Figure C-2. Sensitivity Analysis Matching Plot – Comparison Test Group 1



Source: ComEd billing and tracking data and Navigant team analysis.

Table C-6. Sensitivity Analysis Matching Plot Data – Comparison Test Group 1

Month	MP – 2013/2014 (kWh / day / site)			Pre-Period – 2014/205 (kWh / day / site)		
	Participants	Comparison	Difference	Participants	Comparison	Difference
6	29.60	30.51	-0.91	31.04	31.41	-0.37
7	41.77	42.30	-0.53	38.21	38.75	-0.54
8	38.80	39.51	-0.71	36.52	37.26	-0.74
9	40.47	41.06	-0.60	37.43	37.89	-0.46
10	26.87	27.22	-0.35	23.81	24.28	-0.47
11	24.83	25.20	-0.38	24.17	24.81	-0.63
12	29.93	30.37	-0.43	29.05	29.45	-0.40
1	33.21	33.54	-0.33	31.23	31.74	-0.51
2	32.68	32.74	-0.07	29.45	29.51	-0.06
3	28.97	28.98	-0.02	27.87	28.34	-0.46
4	24.36	24.63	-0.27	22.68	23.22	-0.54
5	23.33	23.72	-0.39	22.74	23.02	-0.28

Source: ComEd billing and tracking data and Navigant team analysis.

C.1.3 Comparison Test Group 2

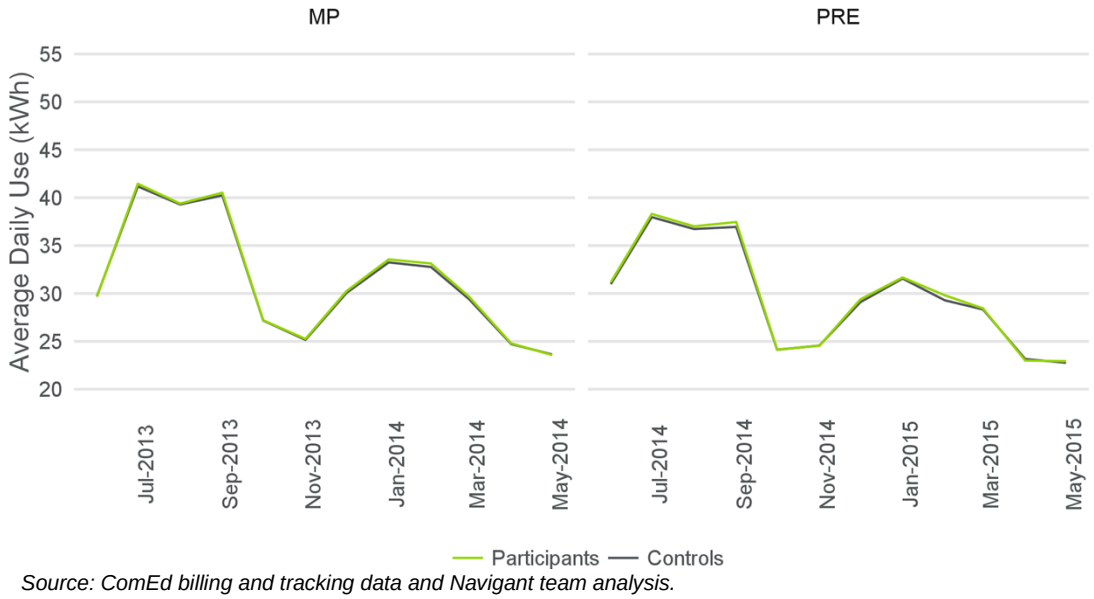
Comparison test group 2 used data from participants and controls that had 10 months of data in the matching period and eight or more months of data in the pre-treatment and post-treatment periods. Participants and controls were matched using the sum of absolute value of difference in energy usage.

Table C-7. Sensitivity Analysis Regression Output – Comparison Test Group 2

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.18	0.004	<0.01	900
CDD	1.68	0.016	<0.01	1,559
Post*	-3.54	0.082	<0.01	-1,292
HDD*Post	0.09	0.003	<0.01	436
CDD*Post	0.60	0.013	<0.01	556
HDD*Treat	0.01	0.005	0.09	43
CDD*Treat	0.05	0.024	0.03	47
Post*Treat	0.40	0.120	<0.01	146
HDD*Post*Treat	-0.03	0.004	<0.01	-136
CDD*Post*Treat	-0.06	0.019	<0.01	-52

Source: ComEd billing and tracking data and Navigant team analysis.

Figure C-3. Sensitivity Analysis Matching Plot – Comparison Test Group 2



Source: ComEd billing and tracking data and Navigant team analysis.

Table C-8. Sensitivity Analysis Matching Plot Data – Comparison Test Group 2

Month	MP – 2013/2014 (kWh / day / site)			Pre-Period – 2014/205 (kWh / day / site)		
	Participants	Comparison	Difference	Participants	Comparison	Difference
6	29.66	29.71	-0.05	31.19	30.97	0.21
7	41.45	41.18	0.28	38.30	37.97	0.33
8	39.39	39.29	0.09	37.01	36.73	0.28
9	40.52	40.24	0.28	37.46	36.95	0.51
10	27.20	27.17	0.03	24.15	24.13	0.02
11	25.25	25.16	0.09	24.54	24.56	-0.02
12	30.24	30.05	0.20	29.38	29.09	0.30
1	33.55	33.24	0.31	31.67	31.56	0.11
2	33.13	32.77	0.36	29.81	29.28	0.52
3	29.66	29.41	0.25	28.44	28.33	0.11
4	24.78	24.71	0.07	22.99	23.15	-0.16
5	23.57	23.63	-0.06	22.93	22.77	0.17

Source: ComEd billing and tracking data and Navigant team analysis.

C.1.4 Comparison Test Group 3

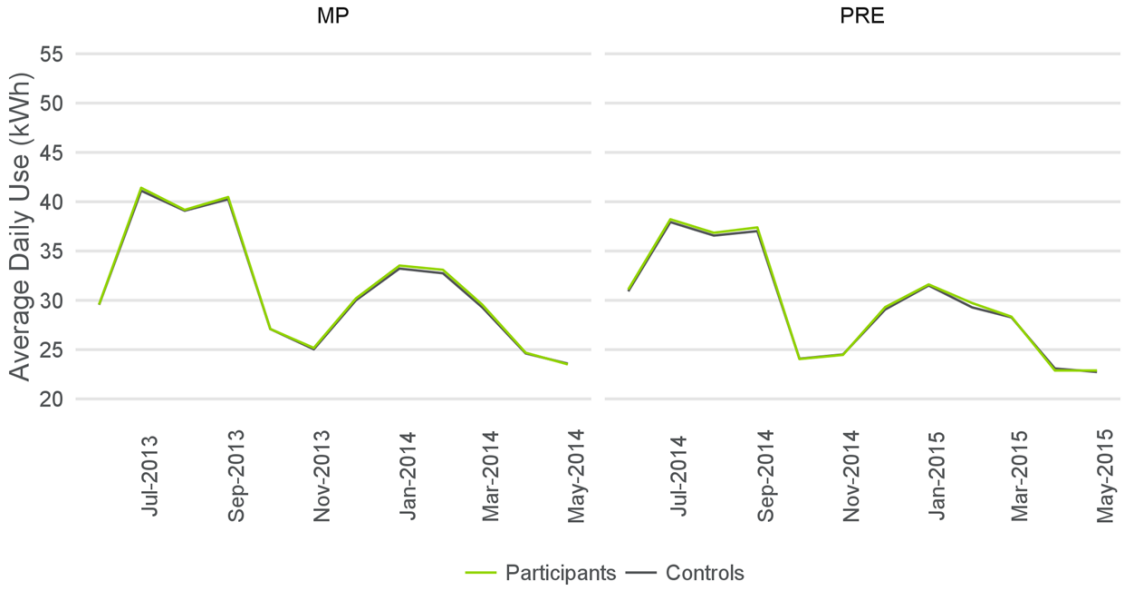
Comparison test group 3 used data from participants and controls that had 10 months of data in each period and were matched using the average squared difference in energy usage.

Table C-9. Sensitivity Analysis Regression Output – Comparison Test Group 3

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.18	0.004	<0.01	898
CDD	1.67	0.017	<0.01	1,551
Post	-3.51	0.083	<0.01	-1,281
HDD*Post	0.09	0.003	<0.01	440
CDD*Post	0.60	0.013	<0.01	559
HDD*Treat	0.01	0.005	0.07	48
CDD*Treat	0.06	0.024	0.02	53
Post*Treat	0.42	0.121	<0.01	152
HDD*Post*Treat	-0.03	0.004	<0.01	-139
CDD*Post*Treat	-0.06	0.019	<0.01	-52

Source: ComEd billing and tracking data and Navigant team analysis.

Figure C-4.Sensitivity Analysis Matching Plot – Comparison Test Group 3



Source: ComEd billing and tracking data and Navigant team analysis.

Table C-10. Sensitivity Analysis Matching Plot Data - Comparison Test Group 3

Month	MP – 2013/2014 (kWh / day / site)			Pre-Period – 2014/205 (kWh / day / site)		
	Participants	Comparison	Difference	Participants	Comparison	Difference
6	29.58	29.55	0.03	31.10	30.91	0.19
7	41.41	41.11	0.30	38.22	37.93	0.29
8	39.17	39.09	0.09	36.85	36.57	0.28
9	40.47	40.25	0.22	37.39	37.02	0.38
10	27.09	27.09	0.00	24.04	24.08	-0.04
11	25.17	25.04	0.14	24.47	24.51	-0.04
12	30.20	30.01	0.19	29.31	29.07	0.24
1	33.52	33.22	0.30	31.61	31.51	0.10
2	33.09	32.74	0.35	29.72	29.28	0.44
3	29.56	29.29	0.27	28.34	28.27	0.06
4	24.68	24.61	0.07	22.88	23.09	-0.21
5	23.50	23.57	-0.07	22.88	22.73	0.15

Source: ComEd billing and tracking data and Navigant team analysis.

C.2 Sensitivity to Model Specification

To ensure model specification accuracy, Navigant conducted sensitivity analyses using different model specifications with the PY8 participant group. Table C-11 identifies the various model specifications used in the sensitivity analyses and Table C-12 presents the results of these analyses. None of the model specifications yielded a higher savings estimate than the total savings for the TRM-recommended participant group (excludes HER effects) shown in Table 5-2. Advanced Thermostat Research Estimated Savings by HER Status

; the savings Navigant is recommending be used to guide updates to the IL TRM.

Table C-11. Robustness Model Specifications

Model	Robustness Check
PY8 participant group	Provided for comparison, no robustness check performed.
Simple Model	Did not include weather in model and used dummy variables and the comparison group to control for non-program effects on energy use
Weather Squared	Added squared HDD and CDD terms to the model
HER Binary	Used a binary dummy variable to identify HER recipients in the post-period
No Post*Treat	Did not include the post*trt interaction variable
No Weather*Post*Treat	Did not include weather (HDD or CDD) interacted with post times treatment

Source: Navigant team analysis.

Table C-12. Sensitivity Analyses Using PY8 Participant Group

Model	Average Daily Usage (kWh)	Average Customer Savings (kWh/yr)	Average Customer Savings Standard Error (kWh/yr)
PY8 participant group	30.35	81.45	31.81
Simple Model	30.35	66.17	32.23
Weather Squared	30.35	58.06	32.02
HER Binary	30.35	81.46	32.59
No Post*Treat	30.35	100.87	29.95
No Weather*Post*Treat	30.35	86.59	32.09

Source: ComEd billing and tracking data and Navigant team analysis.

C.3 Sensitivity to Alternate Data Processing

Navigant conducted a sensitivity analysis to determine the impacts of alternate data processing on estimated savings. In this analysis, weather data was merged into the PY8 participant group analysis dataset by bill date instead of by year and month. Table C-13 presents the estimated savings and Table C-14 presents the regression output for this sensitivity analysis. Estimated savings are not statistically different from those presented in Table 5-2. Advanced Thermostat Research Estimated Savings by HER Status
at the 90% confidence level.

Table C-13. Sensitivity to Alternate Data Processing – Savings Estimates for the PY8 Participant Group with Weather Data Matched by Bill Date

Analysis	Cooling		Heating		Total
	Reduction (%) (90% CI)	Electric Energy Savings by kWh/year/site	Reduction (%) (90% CI)	Electric Energy Savings by kWh/year/site	Electric Energy Savings by kWh/year/site (90% CI)
Evaluation Research Results Group, Matches Weather Data by Bill Date	-0.02% (-1.3 to 1.3%)	-1	4.4% (2.9 to 5.9%)	88	88 (36 to 140)

Source: ComEd billing and tracking data and Navigant team analysis.

Table C-14. Sensitivity to Alternate Data Processing – Regression Output for the PY8 Participant Group with Weather Data Matched by Bill Date

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.27	0.00	<0.01	1,359
CDD	2.08	0.02	<0.01	1,926
Post	-3.47	0.09	<0.01	-1,265
HDD*Post	0.11	0.00	<0.01	567
CDD*Post	0.50	0.01	<0.01	464
HDD*Treat	0.01	0.01	0.02	73
CDD*Treat	0.13	0.03	<0.01	116
Post*Treat	0.48	0.12	<0.01	175
HDD*Post*Treat	-0.03	0.00	<0.01	-166
CDD*Post*Treat	-0.10	0.02	<0.01	-97

Source: ComEd billing and tracking data and Navigant team analysis.

APPENDIX D. ADDITIONAL MATERIALS SUPPORTING ILLINOIS TRM UPDATES

This appendix contains content related to requests from ICC staff meant to provide further detail on the results of the evaluation research and inform updates to the IL TRM.

D.1 Signs of Self-Selection Bias Prior to Program Participation

Navigant searched for diverging trends between comparison and treatment groups before advanced thermostats were installed to investigate whether there were indicators of self-selection bias. Navigant implemented this analysis by using the regression model to compare energy usage impacts between the matching and pre-treatment periods as opposed to between the pre-treatment and post-treatment periods. Navigant conducted this test for both the PY8 participant group and comparison test group 3.

Table D-1 and Table D-2 show the results of this analysis for the PY8 participant group and comparison test group 3, respectively. As shown in the tables, there are two indications that there were not diverging trends during the two years before advanced thermostats were installed. The first indication is that the post treatment variable coefficient values are smaller than what are shown by the regression results in Table C-3. This is most clear in the HDD*Post*Treat term coefficient value; while the coefficient value in Table C-3 is relatively small, an impact is observable. In Table D-1 and Table D-2, the coefficient values for this term are zero indicating that there is no program effect during these time periods. Second, the p-values for the post treatment variables are high, indicating that these terms are not statistically significant. This is in contrast with the statistically significant treatment terms in Table C-3. Subsequently, we see that participants and control customers used energy similarly up until the program intervention.

Table D-1. Time Period Comparison – PY8 Participant Group Regression Output

Variable	Estimate	Standard Error*	P-Value*	Annual Electric Energy Use (kWh/year/site)
HDD	0.28	0.004	<0.01	1,414
CDD	2.18	0.017	<0.01	2,024
Post	2.39	0.072	<0.01	872
HDD*Post	-0.10	0.003	<0.01	-505
CDD*Post	-0.54	0.013	<0.01	-501
HDD*Treat	0.01	0.005	0.15	39
CDD*Treat	0.05	0.025	0.03	49
Post*Treat	-0.12	0.106	0.27	-42
HDD*Post*Treat	0.00	0.004	0.85	-3
CDD*Post*Treat	0.03	0.019	0.10	29

* Error is inaccurate when including the matching period in the regression dataset. Navigant expects the error provided here is biased low, but does not have any indication on the magnitude.
Source: ComEd billing and tracking data and Navigant team analysis.

Table D-2. Time Period Comparison – Comparison Test Group 3 Regression Output

Variable	Estimate	Standard Error*	P-Value*	Annual Electric Energy Use (kWh/year/site)
HDD	0.28	0.004	<0.01	1,398
CDD	2.20	0.016	<0.01	2,039
Post	2.28	0.070	<0.01	832
HDD*Post	-0.10	0.002	<0.01	-500
CDD*Post	-0.53	0.012	<0.01	-489
HDD*Treat	0.01	0.005	0.04	55
CDD*Treat	0.04	0.024	0.12	34
Post*Treat	-0.01	0.104	0.96	-2
HDD*Post*Treat	0.00	0.004	0.66	-8
CDD*Post*Treat	0.02	0.018	0.29	18

* Error is inaccurate when including the matching period in the regression dataset. Navigant expects the error provided here is biased low, but does not have any indication on the magnitude.
Source: ComEd billing and tracking data and Navigant team analysis.

D.2 Results for Non-HER Participants in Comparison Test Group 3 Using Various Models

This subsection contains regression outputs from various models for comparison test group 3, filtered to advanced thermostat participants who did not participate in the HER program. These results were found using the model with the post*treatment term (i.e., the agreed upon model) and a model without the post*treatment term included.

D.2.1 Summary of Comparison Test Group 3, Non-HER Estimated Savings Using Various Models

Table D-3 presents a comparison of the results from a model with and a model without the post*treatment term for non-HER participants in comparison test group 3. Removing the post*treatment term leads to increased cooling savings which are statistically different than zero at the 90% confidence level. To comply with best practices, Navigant supports referencing 2% cooling reduction as the value most applicable from this study to inform IL TRM updates, because it reflects the approach agreed to prior to seeing the analysis results. Conducting analysis under this framework increases transparency and the repeatability of results.

Table D-3. Comparison Test Group 3, Non-HER Participant Estimated Savings Between Models

Model	Cooling		Heating		Total
	Reduction (%) (90% CI)	Electric Energy Savings (kWh/year/site)	Reduction (%) (90% CI)	Electric Energy Savings (kWh/year/site)	Electric Energy Savings (kWh/year/site) (90% CI)
With Post*Treatment	1.7% (-1.8 to 5.3%)	34	6.0% (1.7 to 10.4%)	77	111 (7 to 214)
Without Post*Treatment	3.2% (0.9 to 5.5%)	61	5.3% (0.5 to 10.2%)	66	58 (-20 to 135)

Source: ComEd billing and tracking data and Navigant team analysis.

D.2.2 Comparison Test Group 3, Non-HER Participant Characteristics and Data Processing

In preparation for this analysis, Navigant processed non-HER participant data by removing customers and data points from the analysis in the steps identified in Table D-4.

Table D-4. Comparison Test Group 3, Non-HER Participant Site Attrition

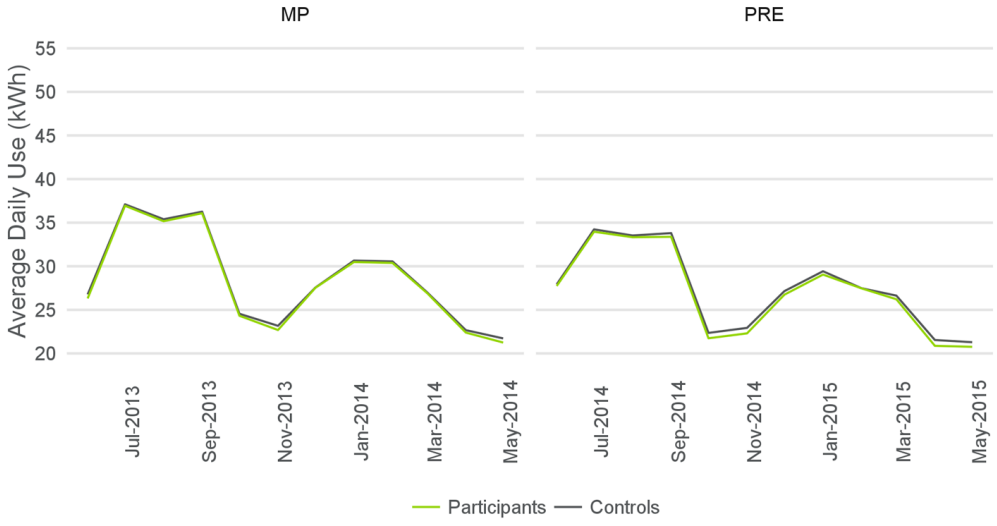
Data Processing Step	Participants	Controls
Raw Data	23,884	1,946,260
Filter to non-HER participants	10,202	275,409
Bad Reads (e.g., All Estimated Bills)	10,202	275,408
Averaged Bills in the Same Month	10,202	275,408
Removed Outliers (i.e., observations one order of magnitude above or below median usage)	10,202	275,383
Had 10+ Observations in Pre- and Post-Periods	3,932	186,474
Received No Other Rebates or Rebated Measures from Res HVAC or HEA Programs	3,399	179,226
Had Matches in same HER Wave and Zip	3,399	164,173
Had 10+ Observations in the Matching Period	2,641	155,610

Source: ComEd billing and tracking data and Navigant team analysis.

D.2.3 Comparison Test Group 3, Non-HER Participant Matching

This subsection contains information on the participant matching for comparison test group 3, non-HER participants. Figure D-1 presents a plot of average monthly usage for participants and controls in the matching and pre-treatment periods and Table D-5 presents the numerical values used to create the plot.

Figure D-1. Comparison Test Group 3, Non-HER Participant Matching Plot



Source: ComEd billing and tracking data and Navigant team analysis.

Table D-5. Comparison Test Group 3, Non-HER Participant Matching Data

Month	MP – 2013/2014 (kWh / day / site)			Pre-Period – 2014/205 (kWh / day / site)		
	Participants	Comparison	Difference	Participants	Comparison	Difference
6	26.31	26.77	-0.46	27.74	27.93	-0.19
7	36.94	37.10	-0.17	33.96	34.23	-0.27
8	35.17	35.39	-0.22	33.33	33.53	-0.20
9	36.08	36.26	-0.18	33.38	33.80	-0.42
10	24.32	24.55	-0.23	21.74	22.36	-0.62
11	22.69	23.17	-0.48	22.30	22.93	-0.63
12	27.52	27.55	-0.03	26.74	27.15	-0.41
1	30.48	30.65	-0.17	29.05	29.43	-0.38
2	30.38	30.56	-0.18	27.46	27.48	-0.01
3	26.90	26.99	-0.09	26.22	26.63	-0.42
4	22.39	22.67	-0.28	20.87	21.54	-0.67
5	21.25	21.72	-0.48	20.76	21.29	-0.53

Source: ComEd billing and tracking data and Navigant team analysis.

D.2.4 Comparison Test Group 3, Non-HER Regression Output

Table D-6 provides regression output from the model with the post*treatment term and Table D-7 presents regression output from the model without the post*treatment term.

Table D-6. Comparison Test Group 3, Non-HER Participant Regression Output – With Post*Treatment Term

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.17	0.009	<0.01	856
CDD	1.40	0.033	<0.01	1,295
Post*	-2.74	0.167	<0.01	-1,000
HDD*Post	0.07	0.006	<0.01	366
CDD*Post	0.63	0.026	<0.01	585
HDD*Treat	0.01	0.012	0.31	62
CDD*Treat	0.07	0.047	0.11	69
Post*Treat	0.27	0.242	0.26	99
HDD*Post*Treat	-0.02	0.009	0.01	-116
CDD*Post*Treat	-0.10	0.036	0.01	-93

Source: ComEd billing and tracking data and Navigant team analysis.

Table D-7. Comparison Test Group 3, Non-HER Participant Regression Output – Without Post*Treatment Term

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.17	0.009	**<0.01**	868
CDD	1.41	0.033	<0.01	1,304
Post*	-2.60	0.121	<0.01	-951
HDD*Post	0.07	0.006	<0.01	341
CDD*Post	0.61	0.024	<0.01	569
HDD*Treat	0.01	0.012	0.52	40
CDD*Treat	0.05	0.048	0.25	51
HDD*Post*Treat	-0.01	0.008	0.08	-66
CDD*Post*Treat	-0.07	0.030	0.03	-61

Source: ComEd billing and tracking data and Navigant team analysis.

D.3 Analysis of Heating and Cooling Loads Between Comparison Groups

Navigant also conducted an analysis around heating and cooling loads between participants and comparison group customers before advanced thermostats were installed. Table D-8 and Table D-9 contain weather variable regression output for the PY8 participant group and comparison test group 3, respectively. These results indicate a difference of approximately 4% of heating and cooling use between comparison and treatment groups before households received advanced thermostats. The savings model controls for this difference in weather sensitivity as shown in the results for the HDD*treat and CDD*treat variables.

Table D-8. PY8 Participant Group Matches Weather Variable Regression Output

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.24	0.00	<0.01	1,188
CDD	1.93	0.02	<0.01	1,785
HDD*Treat	0.01	0.01	0.08	44
CDD*Treat	0.08	0.02	<0.01	78

Source: ComEd billing and tracking data and Navigant team analysis.

Table D-9. Comparison Test Group 3 Matches Weather Variable Regression Output

Variable	Estimate	Standard Error	P-Value	Annual Electric Energy Use (kWh/year/site)
HDD	0.24	0.00	<0.01	1,181
CDD	1.96	0.02	<0.01	1,820
HDD*Treat	0.01	0.01	0.04	51
CDD*Treat	0.05	0.02	0.04	43

Source: ComEd billing and tracking data and Navigant team analysis.