ComEd Advanced Thermostat Evaluation

Final Research Report

November 10, 2020

Authors

Jason Lai
Managing Consultant
jason.lai@guidehouse.com
(416) 203-9173

Bethany Glinsmann
Managing Consultant
bethany.glinsmann@guidehouse.com
(608) 616-4768

Carly Olig
Associate Director
carly.olig@guidehouse.com
(608) 616-4810

Jeff Erickson
Director
jeff.erickson@guidehouse.com
(608) 616-4962

Randy Gunn
Partner
randy.gunn@guidehouse.com
(312) 583-5714

Guidehouse

Table of Contents

Glossary

AMI	Advanced Metering Infrastructure
CDD	Cooling Degree Days
ELPC	Environmental Law and Policy Center
FE	Fixed Effect
HER	Home Energy Report
HVAC	Heating, Ventilation, and Air Conditioning
ICC	Illinois Commerce Commission
IL TRM	Illinois Technical Reference Manual
ISR	In-Service Rate
LDV	Lagged Dependent Variable
RCT	Randomized Controlled Trial
RED	Randomized Encouragement Design
SAG	Stakeholder Advisory Group
TAC	Technical Advisory Committee
TO	Thermostat Optimization
TMY	Typical Meteorological Year
VEIC	Vermont Energy Investment Corporation

Research Objectives

This research focused on Advanced Thermostats (measure 5.3.16 of the Illinois Technical Reference Manual (IL TRM)). The goals of this study included:

- Producing evaluated estimates of annual cooling electric savings and coincident peak demand savings*, which were available to inform the Technical Advisory Committee (TAC) update process, coordinated by Vermont Energy Investment Cooperative (VEIC), for version 9.0 (v9) of the IL TRM
- Research to understand and contextualize the findings, including understanding those that were unexpected, such as the effect of advanced thermostats on non-weather-related energy use

This research focused on the following key questions:

- What is the impact of residential advanced thermostats on cooling season electric consumption?
- What is the impact of residential advanced thermostats on electric demand during coincident peak periods?*
- How do these estimates compare between two different methods: (1) an econometric analysis and (2) an adjusted ENERGY STAR analysis?

* The summer coincident peak period is defined as 1-5 PM on non-holiday weekdays from June – August. See IL TRM, v9, volume 1, page 54.

Guidehouse

IL TRM v7 Stipulation

This research is partially motivated by a stipulation signed as part of the update process for v7 of the IL TRM. In October 2018, the following parties reached an agreement as part of that update process, which retained the 8% cooling reduction value in v7: Ameren Illinois Company, Commonwealth Edison, Illinois Attorney General's Office, Staff of the Illinois Commerce Commission (ICC), Natural Resources Defense Council, Environmental Law and Policy Center (ELPC), and Citizen's Utility Board. The full text of the stipulation is reproduced below.

The undersigned parties (the "Stipulating Parties") have agreed to the following:

> In an effort to resolve potential disputes regarding the cooling reduction value in the IL-TRM for advanced thermostats, the Stipulating Parties agree to retain the 8% cooling reduction value for the 2019 IL-TRM Version 7.0, subject to completion of a statewide advanced thermostat evaluation utilizing AMI data. Specifically, the Stipulating Parties agree to work collaboratively with ComEd independent evaluator Navigant and Ameren Illinois independent evaluator Opinion Dynamics and other interested stakeholders to develop an Illinois-specific advanced thermostat evaluation method(s) that utilizes pre- and post-advanced thermostat participant AMI data and is developed with consideration of all proposed evaluation strategies, consistent with best industry practices, to be completed as soon as feasible for consideration in updating the IL-TRM. In developing the evaluation strategy, consideration will be given to adopting approaches that estimate cooling run time changes from the actual participants' pre-advanced thermostat AMI data, along with actual post-advanced thermostat run time data provided by both the thermostat manufacturers and AMI data, as well as performing an econometric analysis on the AMI data using total home electricity consumption rather than estimated run time to provide another estimate and a comparison between the two methods. The Stipulating Parties further agree that nothing in this agreement precludes consideration of other evaluation approaches.

Below is proposed language that would be included as a footnote next to an 8% cooling reduction value for advanced thermostats in the 2019 IL-TRM Version 7.0:

> In an effort to resolve potential disputes, without the need for litigation regarding the cooling reduction value in the IL-TRM for advanced thermostats, Stakeholders have reached through negotiation a separate stipulation that retains the 8% cooling reduction value in the 2019 IL-TRM Version 7.0, pending completion of a statewide advanced thermostat evaluation utilizing participant AMI data, and consistent with a Stipulation reached among stakeholders and the Program Administrators. Specifically, the parties have agreed to work collaboratively to develop an Illinois-specific advanced thermostat evaluation framework that utilizes AMI data, for consideration in updating the IL-TRM as soon as feasible, but no later than completing the evaluation in time for the 2021 IL-TRM Version 9.0, if practicable and, for Ameren Illinois, in a manner consistent with the timing of its AMI installation schedule.

Coordination with Stakeholders

Guidehouse engaged with both the Opinion Dynamics (evaluator for Ameren Illinois) and the Advanced Thermostat Subcommittee to collaboratively develop Illinois-specific advanced thermostat evaluation methods in support of updates to IL TRM v9. The Advanced Thermostat Subcommittee included the Stipulation Parties as well as members of other organizations interested in this research, such as Guidehouse, Opinion Dynamics, ICC staff, VEIC, ComEd, Ameren, Google, Ecobee, and the ELPC. Coordination involved:

- Regular meetings with Opinion Dynamics to coordinate and discuss methods and results
- 14 touchpoint meetings with the Advanced Thermostat Subcommittee between September 2018 and August 2020
- 10 comment and response periods, to solicit written comments from stakeholders
- 1-on-1 meetings with stakeholders as necessary

All subcommittee correspondence can be found on the IL TRM Sharepoint website here:

- https://portal.veic.org/projects/illinoistrm/Shared%20Documents/Working%20Group%20Materials/Advanced%20Thermostat%20Subcommittee/Communications/2019%20Adv%20Therm%20Research

Please contact the IL TRM Administrator for access: iltrmadministrator@veic.org

Analysis Pathways

In accordance with the IL TRM v7 Stipulation, Guidehouse pursued two analysis pathways in collaboration with the Advanced Thermostat Subcommittee:

1. **Econometric Analysis:** Utilized AMI data to create a quasi-experimental evaluation design, comparing the difference in cooling electric energy use before and after installation of an advanced thermostat using a comparison group comprised of future participants.
2. **Adjusted ENERGY STAR Analysis:** The EPA's ENERGY STAR program prescribes a method for demonstrating field savings (HVAC runtime) for connected thermostats.* Some stakeholders expressed a strong desire to leverage this method for evaluation purposes. Guidehouse, in collaboration with Opinion Dynamics and stakeholders, developed adjustments to the ENERGY STAR method to potentially improve the accuracy of the method, subject to the data available and the timeline prescribed by the IL TRM v7 Stipulation.

* ENERGY STAR Connected Thermostat Products Method to Demonstrate Field Savings Version 1.0 (rev. Dec-2016). Available at: https://www.energystar.gov/sites/default/files/Version%201.0%20Method%20to%20Demonstrate%20Field%20Savings%20of%20ENERGY%20STAR%20Connected%20Thermostats.pdf

Advanced Thermostats Agreement for IL TRM v9

- In September 2020, stakeholders reached agreement regarding consensus on the cooling reduction value for advanced thermostats for the IL TRM v9.
- Specifically, in an effort to resolve any remaining potential disputes regarding the cooling reduction value for advanced thermostats, the Stipulating Parties agreed that 8.42% will be used as the updated cooling reduction value for advanced thermostats in the IL TRM v9, in fulfillment of the October 2018 Stipulation.
- The 8.42% is based on a specific weighting, agreed upon by the Stipulating Parties, of the econometric and adjusted ENERGY STAR metric values produced by the research documented in this report. The result is the econometric result (7.8%) weighted at 90%, and the ENERGY STAR result (10-14% range chosen as reasonable by stakeholders; however 14% is used to account for increased Thermostat Optimization* (TO)) weighted at 10%.
  - The rest of this report can be read with this end conclusion in mind.

* Thermostat Optimization refers to opt-in programs such as Nest Seasonal Savings and ecobee eco+, which algorithmically optimize users' thermostat to save additional HVAC usage.

Summary and Recommendations

Guidehouse

Econometric Analysis Summary

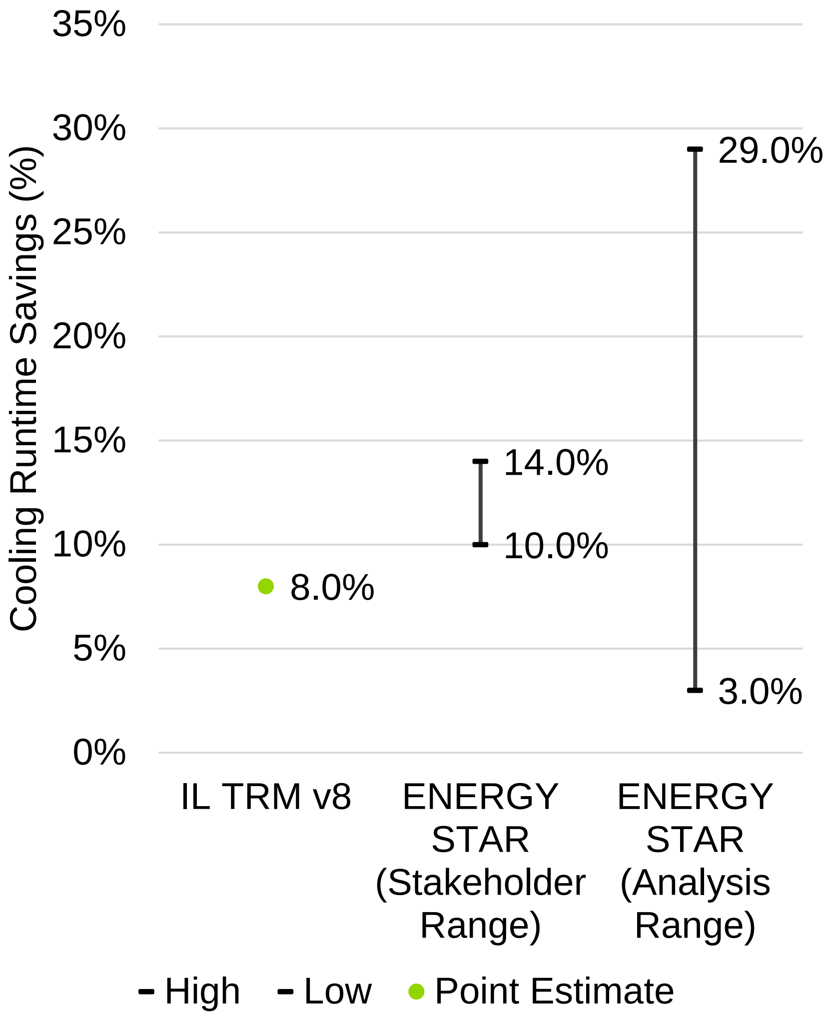
Result	Energy Savings (Percent of Cooling Load)		Coincident Peak Demand Savings (Percent of Cooling Load)	
	Non-Selection Adjusted	Selection Adjusted	Non-Selection Adjusted	Selection Adjusted
Regression Model	3.24%	-	10.37%	-
Fully Adjusted	6.36%	7.79%	15.70%	16.41%

- On average, study participants getting an advanced thermostat rebate saved energy. This result is based on study participants who are enrolled in the Home Energy Report (HER) program.*
- Savings are concentrated during daytime hours, when customers are likely to be away from home, leading to substantial coincident peak demand savings (1-5 PM on non-holiday weekdays, June – August).
- “Fully Adjusted” results include adjustments that were not able to be directly incorporated into the regression model due to data constraints, including:
  - Customers who are assumed to not have connected AC, or who installed their thermostat during or after the study period
  - Wider deployment of TO algorithms, beginning in 2020, after the study period
  - Additional details are provided in the results section.
- “Selection Adjusted” refers to adjustment for potential selection bias, per stakeholder request. Guidehouse acknowledges that this adjustment is a coarse method of addressing potential bias but believes that it may not be accurate or applicable for future studies of this type.

* Additional details are provided in the results section.

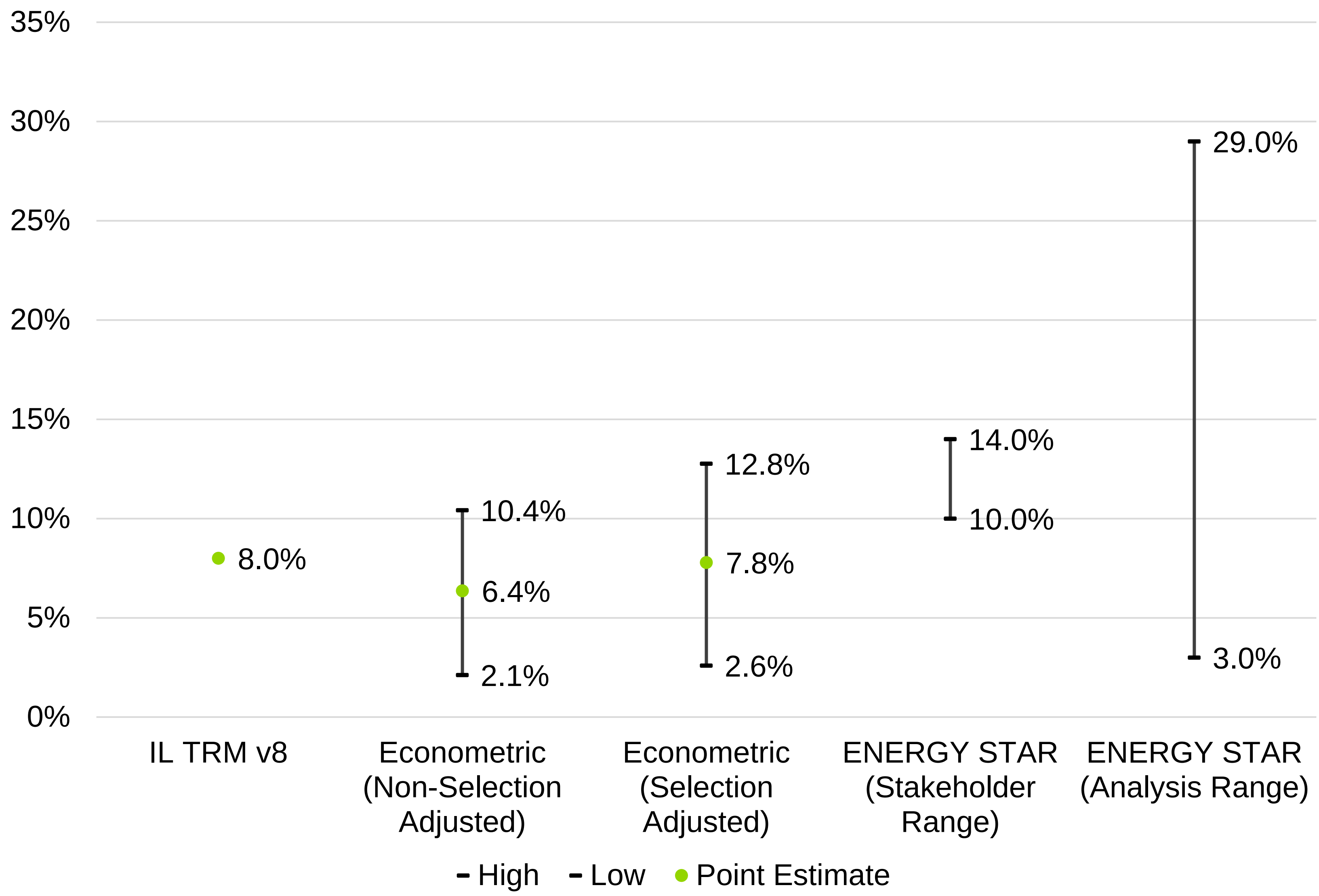
ENERGY STAR Analysis Summary

- Guidehouse developed adjustments to the ENERGY STAR method, focusing on:
  - Baseline comfort temperature – Testing different methods for selecting the baseline setpoint in absence of an advanced thermostats. The ENERGY STAR method assumes that a customer would use a constant temperature set point, equivalent to the 10th percentile of their post-installation temperature history.
  - Setback behavior – Testing a range of baseline setpoint changes from 0 to +4°F for the period during the day when no one is home, 8 AM to 5 PM on weekdays.
- Guidehouse estimated a range of runtime savings based on survey responses regarding how customers used their thermostat before advanced thermostat installation.
  - Assumptions used were selected to provide context on the range of savings that could be expected, as well as the sensitivity of savings to different assumptions (e.g. the effect of a setback on savings).
- Savings estimates for analyzed scenarios range from 3% to 29% of cooling runtime.
  - Guidehouse acknowledges that some stakeholders assert a range of parameters that they consider to be a reasonable range of expected behavior, which results in savings estimates between 10% and 14% of cooling runtime. The evaluators did not have data to verify these estimates; however, stakeholders may consider whether this range is sufficient for informing the IL TRM.
- Guidehouse found similar savings estimates for both HER and non-HER participants.
- Guidehouse did not estimate coincident peak demand savings using the ENERGY STAR method.
- Additional details are provided in the detailed results section.



Comparison of Analyses (Energy Savings)

- Savings estimates from the econometric analysis are shown with those from the ENERGY STAR analysis and IL TRM v8
  - All econometric and ENERGY STAR estimates are based on 2018 weather
  - Econometric results include all post-regression adjustments
- The two analyses are different in a number of ways, summarized on the next slides. Caution should be used when comparing these savings estimates.



Guidehouse

Comparison of Analyses (Continued)

The following table (continued on the next slide) summarizes the features and differences of both analyses.

Category	Econometric	ENERGY STAR
Sample Population	• 13,388 study participants, 22,630 future participants • Entire population is HER participants • Includes thermostats from multiple manufacturers	• 500 participants (250 HER, 250 Non-HER) from one manufacturer
Key Data	• Whole-home consumption Advanced Metering Infrastructure (AMI) data (half hourly kWh) • Aggregated to hourly for comparison group selection and daily for regression analysis • Includes 2017 (pre-installation) and 2018 (post-installation) data • PRIZM demographic customer segmentation	• Thermostat telemetry data (e.g. hourly cooling runtime, set point) • Includes 2018 (post-installation) data • Participant survey responses (inform assumed set point behavior)
Estimation Method	• Lagged Dependent Variable (LDV) model using participants and a comparison group of future participants • Estimates difference between pre- and post-consumption attributable to the smart thermostat	• Site-specific Heating, Ventilation, and Air Conditioning (HVAC) model (function of indoor / outdoor temperature) • Estimates difference between actual post-runtime and estimated pre-runtime based on assumed baseline behavior • Adjusted for different scenarios of baseline behavior, including different preferred comfort temperature and setbacks.
Savings Output	• Average whole-home energy savings	• Average HVAC runtime savings

Comparison of Analyses (Continued)

The following table (continued from the previous slide) summarizes the features and differences of both analyses.

Category	Econometric	ENERGY STAR
Conversions for IL TRM	• Convert whole home to cooling load energy savings • Adjustments for customers without connected AC • Adjustments for customers who installed during or after study period • Adjusted for expected future TO savings (as applicable) due to wider deployment	• Convert runtime to energy savings
In-Service Rate	• Uses separate in-service rate (ISR)	• Uses separate ISR
Net to Gross *Gross – not accounted for* *Net – fully accounted for*	• Free-ridership: gross* • Participant spillover: net* • Non-participant spillover: gross* • Applicable net-to-gross adjustments to these factors were determined as part of the annual Stakeholder Advisory Group (SAG) net-to-gross process	• Free-ridership: gross • Participant spillover: gross • Non-participant spillover: gross • Applicable net-to-gross adjustments to these factors were determined as part of the annual SAG net-to-gross process
Additional Considerations	• Potential self-selection issues related to time of installation (now vs future)	• ENERGY STAR model doesn’t capture potential secondary effects (e.g. increased fan consumption, more energy efficient behavior, or other spillover effects) • Includes only historical TO savings (if applicable)

* In IL TRM v8, Volume 4, Section 5.3.1, Table 5-3, regression using a comparison group of future participants produces an estimate that is gross to free ridership and non-participant spillover but net to participant spillover.

Guidehouse

Findings and Recommendations

Guidehouse makes the following recommendations based on this research. Note that the final decisions regarding updates to IL TRM v9 were determined by the TAC and agreement by Stipulating Parties. The Advanced Thermostats Agreement for IL TRM v9 describes the agreement reached regarding the cooling reduction factor.

	Finding	Recommendations

1	• Electric cooling savings (7.8%) attributed to advanced thermostats via the econometric analysis, after adjustment, are similar to what is defined in the IL TRM v8.
	• The range of electric cooling savings estimated via the ENERGY STAR analysis (10-14% stakeholder estimated range) is materially different than the econometric analysis. This difference could be due to:
	  • Pre-installation behavior that was not able to be incorporated into the ENERGY STAR analysis, and/or
	  • Uncertainty with respect to the comparison group used for the econometric analysis, related to potential time-based selection bias or other pre-existing differences.
		• See the Advanced Thermostats Agreement for IL TRM v9 for details on the decision for updating the cooling reduction factor.

2	• The econometric analysis and Google activation data suggests that some participants who receive a rebate for an advanced thermostat may delay installation, installed the device out of state, or never install the device at all.	• The TAC should consider updating the ISR for customer self-install programs for estimating cooling savings in the IL TRM v9, based on Google activation data. • Guidehouse recommends using an estimated ISR of 90%, determined through discussions with VEIC.

Findings and Recommendations (Continued)

Guidehouse makes the following recommendations based on this research. Note that the final decisions regarding updates to IL TRM v9 were determined by the TAC and agreement by Stipulating Parties. The Advanced Thermostats Agreement for IL TRM v9 describes the agreement reached regarding the cooling reduction factor.

	Finding	Recommendations
3	• While both parallel studies have imperfections, Guidehouse considers the econometric analysis to be more robust due to the inclusion of measured pre-period consumption data. • Guidehouse does not consider the ENERGY STAR analysis to be sufficiently robust for evaluation purposes. – Guidehouse acknowledges that stakeholders asserted a range of parameters that they consider to be a reasonable range of expected behavior, which results in savings estimates between 10% and 14% of cooling runtime. The evaluators did not have data to verify these estimates; however, stakeholders may consider whether this range is sufficient for informing the IL TRM. • True customer behavior may not be fully accounted for in the assumptions made for the adjusted ENERGY STAR analysis. The analysis is based on assumptions informed by survey data and discussion with Stakeholders, rather than measured pre-installation behavior (e.g. set points over time). • The econometric analysis includes pre-installation behavior via pre-period consumption data but cannot fully remove potential selection bias without true experimental design. Additionally, Guidehouse was unable to find a high-quality comparison group for non-HER customers.	• To increase the accuracy of the adjusted ENERGY STAR method, ***incorporate measured pre-installation behavior*** to produce savings estimates more reflective of actual pre-period behavior than current assumptions. The evaluators believe this would lead to a more defensible result. • Measured data may include (but is not limited to), ***pre-installation set points, indoor temperature, and HVAC unit energy consumption for baseline homes.*** Such data is not currently available and would need to be collected. • To remove uncertainty associated with evaluation using a comparison group, ***utilities should consider implementing advanced thermostat programs with an experimental design*** (e.g. a Randomized Controlled Trial (RCT) or Randomized Encouragement Design (RED)).

Findings and Recommendations (Continued)

Guidehouse makes the following recommendations based on this research. Note that the final decisions regarding updates to IL TRM v9 were determined by the TAC and agreement by Stipulating Parties. The Advanced Thermostats Agreement for IL TRM v9 describes the agreement reached regarding the cooling reduction factor.

	Finding	Recommendations
4	• Based on the econometric analysis, savings occurred during daytime hours (9 AM – 5 PM), when users are most likely to be away from home. • Consumption appeared to increase during non-daytime hours (5 PM – 9 AM) after the rebate of an advanced thermostat, which could indicate comfort takeback and/or cooling load shifting behavior. This could also suggest the presence of selection bias. • Guidehouse's analysis for the defined peak period (June – August, non-holiday weekdays, 1-5 PM) showed statistically significant coincident peak demand savings.	• The TAC should consider updating coincident peak demand savings in the IL TRM, ***referencing 15.7% or 16.4% cooling reduction***, depending on stakeholder consideration for "selection adjustment", and ***apply the same savings value to HER participants and non-participants.***
5	• Assumed full load hours cooling load are based on a ComEd Program Year 2 (PY2) Central Air Conditioner evaluation and are weather-normalized using Typical Meteorological Year 2 (TMY2) data. • The IL TRM v8 uses the 30-year climate normal (1981-2010) to weather-normalize impacts for all applicable measures.	• The TAC should consider updating the assumption for full load hours in a future IL TRM update. • The TAC should consider updating the standard weather used for estimating impacts in a future IL TRM update to include more recent weather years.

Econometric Analysis Results

Guidehouse

Overview

- The objectives of the econometric analysis were to estimate annual cooling electric savings and coincident peak demand savings.
- Guidehouse performed a regression analysis of AMI data for ComEd participants who received a rebate for an advanced thermostat between October 2017 and March 2018, to estimate savings over the 2018 cooling season (May – September 2018)
  - In the analysis, Guidehouse leveraged a comparison group of future ComEd participants who received a rebate for an advanced thermostat after September 2018. The purpose of a comparison group is to account for trends in energy use that are not related to the rebate of an advanced thermostat.
  - Study and future participants who are enrolled in the HER program are well balanced with respect to usage in the pre-rebate summer and demographic characteristics. Further refinements via matching were not required. Additional details on the balance checks are available in the Appendix.
  - Guidehouse was unable to find a high-quality comparison group for non-HER customers. Savings estimates from the econometric analysis are based on study participants who are enrolled in the HER program. Additional details on the non-HER customers are available in the Appendix.
- Guidehouse adjusted estimated savings based on factors that could not be directly incorporated into the regression analysis due to data or other limitations, including:
  - Customers who are assumed to not have connected AC, or who installed their thermostat during or after the study period
  - Wider deployment of TO algorithms, beginning in 2020, after the study period
  - Additional details are provided in the results section.
- Additional details on the econometric methodology can be found in the Appendix.

Study Period and Population

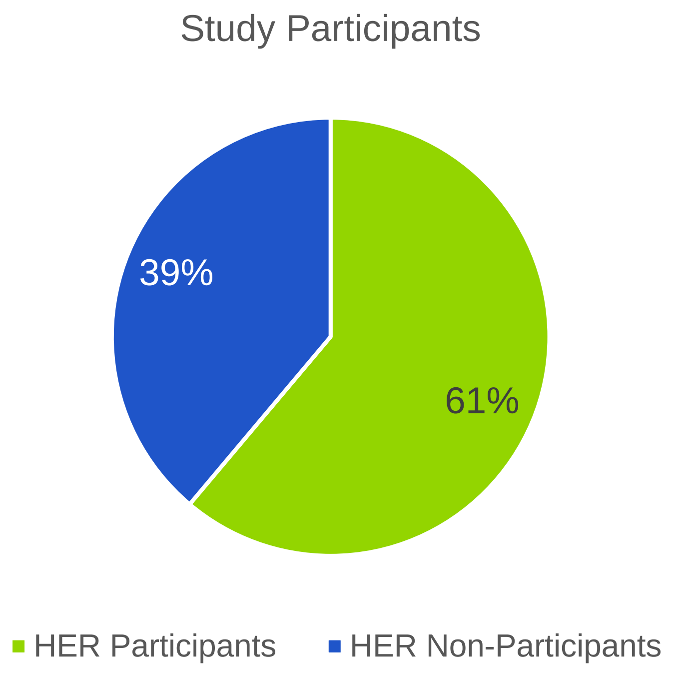
- Participants are customers who received a rebate for an advanced thermostat through a number of ComEd programs.*
  - Participants (Study and Future) who installed other measures in PY9, CY2018, or CY2019 were excluded (11.5%), to mitigate the effect of installing other measures. Additional details are available in the Appendix.
- We assume that the rebate application date coincides with thermostat installation, although there may be a time difference (e.g. a person may install their thermostat before / after applying for their rebate).
  - To account for potential delayed installations, this study leaves a month between the last rebate date for study participants (March 2018) and the beginning of the post-period (May 2018).
  - As some customers delay or do not install their thermostats, the results of the econometric analysis adjusted for customers who installed during or after the study period; Guidehouse does not have account level installation data to remove these customers from the sample outright.
- After cleaning, the data available for the analysis included 21,896 study participants and 42,539 future participants.†

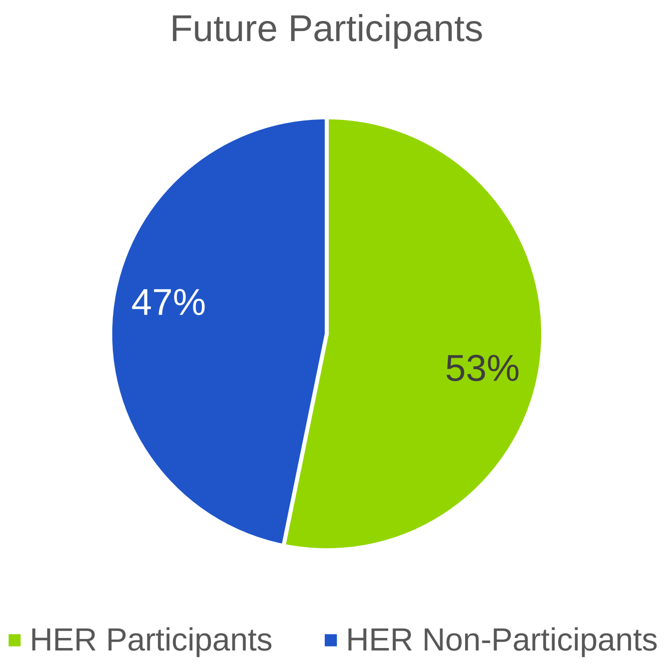
* The list of relevant programs is available in the Appendix.
† A summary of the data cleaning process is available in the Appendix.

HER Enrollment

HER enrollment rates differ for study and future participants

- Study participants are more likely than future participants to be assigned to an HER wave.
  - 61% of study participants are enrolled in HER
  - 53% of future participants are enrolled in HER
- To account for differences in HER participation rates, Guidehouse analyzed HER participants and non-participants (including HER controls) separately.





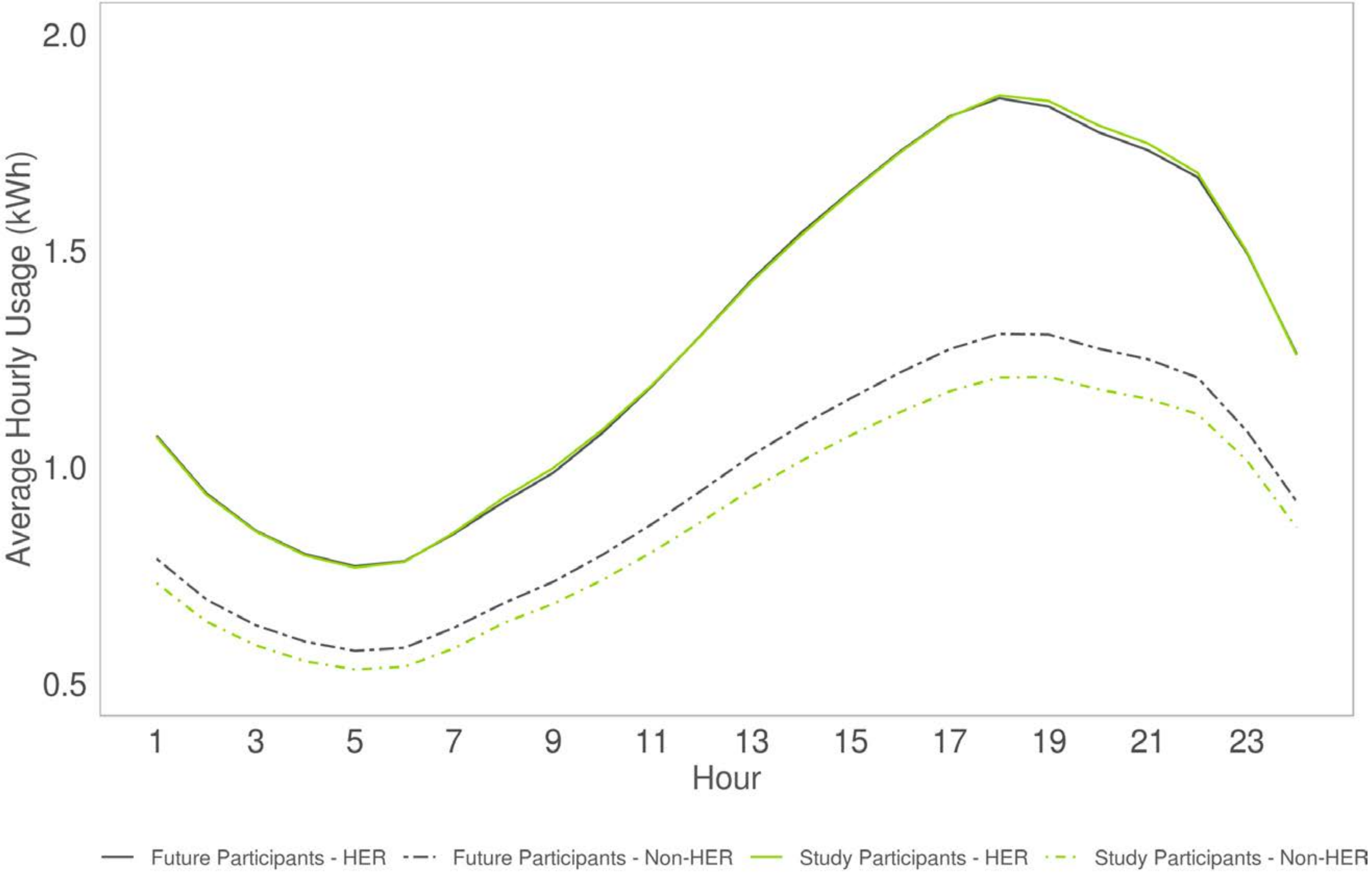
Customer Counts	HER	Non-HER
Study	13,388	8,508
Future	22,630	19,909

Note: HER control customers are included in the non-HER group.

HER Enrollment

Hourly Load Shapes in Pre-Rebate Summer

- Study and future participants who are enrolled in the HER program are well balanced in the pre-rebate summer. Further refinements via matching were not required.
  - Average hourly load differs by less than 1.1% in all hours.
  - The largest differences occur during the hours of 7-9 AM and 6-11 PM
  - The groups are well balanced in terms of demographic characteristics, as shown in the Appendix.
  - Demographic variables are included in the regression model to account for remaining discrepancies as much as possible.
- Study and future participants who are not enrolled in the HER program are *not* well balanced in the pre-rebate summer. Therefore, Guidehouse explored further refinements via matching.



HER Non-Participant Matching

Guidehouse explored matching methods for HER non-participants but was unable to identify a comparison group of sufficient quality.

- Guidehouse examined several matching methods, as detailed in the Appendix.
  - Matching methods encompass combinations of exact matching on HER wave group and demographics, followed by Euclidean distance matching on usage in the pre-rebate summer.
- Although matching reduced the difference in average pre-rebate usage by about half (from approximately 7.5% to approximately 3%, averaged across all hours) for HER non-participants, **the matched comparison groups are not of sufficient quality to use in the analysis.**
- Although the HER non-participant matched comparison groups are not of sufficient quality, Guidehouse estimated savings using our preferred model with the four matched comparison groups. Savings were found to be negative (implying advanced thermostats increased usage) and statistically significant in all four cases. **Due to poor match quality, Guidehouse does not recommend using these values.**
- Guidehouse recommends applying the savings estimate for HER participants to all customers.
- Details on the match quality and savings estimates are provided in the Appendix (Matching, Savings Estimates).

Summary of Regression Models

- Guidehouse's preferred model specification is the LDV model.
- Based on stakeholder feedback, Guidehouse estimated a number of different model types in order to assess the robustness of savings estimates.
- All models leverage daily usage data. Full model specifications are available in the Appendix.

Lagged Dependent Variable (LDV) ***Preferred**	Fixed Effects (FE)	Within-Subject ("Pre-Post")
• Average usage during the pre-installation period, by month and weekday • Controls for month, weekends, weather, and demographics • Savings allowed to vary by weather and weekday/weekend	• Customer-level fixed effects • The fixed effect inherently captures demographics • Daily fixed effects • Controls for weather • Savings allowed to vary by weather and weekday/weekend	• ***Note: Guidehouse does not recommend this model, but tested it based on stakeholder request.*** • Estimated separately for study participants and future participants • Customer-level fixed effects • Controls for weekends and demographics • Savings allowed to vary by weather and weekday/weekend

Estimating Cooling Load

Guidehouse

Estimating Cooling Load Savings

Overview

- The results of the econometric analysis are intended to support updating the Cooling Reduction factor in the IL TRM equation, which is savings as a percentage of cooling load.
- Since the econometric analysis produces an estimate of whole home energy savings, Guidehouse needed an estimate of cooling load to develop an estimate of percentage cooling savings.

From IL-TRM Version 8.0 Volume 3: Residential Measures, Section 5.3.16 Advanced Thermostats, p. 167:

Assumed Annual Energy Consumption

Derive Percentage Cooling Energy Savings

Energy Savings, from econometric analysis →

$$\Delta kWh_{cool} = \%AC \times \frac{FLH \times Capacity}{SEER \times 1000} \times Cooling\_Reduction \times Eff\_ISR$$

← **Effective In-Service Rate**

% of Customers with Thermostat-Controlled AC

Estimated Cooling Load

- Guidehouse assessed the estimate of cooling load via three different methods (see Appendix for more details):
  - **IL TRM formula**: based on estimated full load hours*, capacity, and efficiency†
  - **Regression Analysis of AMI Data**: use a regression model with study participants with weather terms to estimate weather-dependent usage (i.e., disaggregate counterfactual cooling load)
  - **Thermostat Telemetry Data**: convert HVAC runtime to energy usage for the aggregated telemetry data for Illinois participants (data supplied by Google)

Source	Weather	Estimated Seasonal Cooling Load (kWh)	% Difference from IL TRM formula
IL TRM v8 Formula*	-	1,523.1	-
AMI Regression Model (Study Participants)	2018	2,244.3	+47.4%
Thermostat Telemetry Data (Aggregate)	2018	1,882.7	+23.6%

- Stakeholders expressed a preference for not using the IL TRM formula for calculating cooling load, but instead using actual 2018 weather and consumption. Therefore, **Guidehouse recommended using the aggregate thermostat telemetry data to estimate cooling load**.

* The IL TRM formula provides full load hours for annual cooling consumption; however, the majority of cooling occurs during May through September, the same months used for the other estimation methods.

† Per stakeholder feedback and discussion with VEIC, Guidehouse used a default SEER value of 12 to represent installed equipment for estimating cooling load.

Estimated Savings: Regression Analysis Results

Guidehouse

Limitations (Selection Bias)

- Some stakeholders have raised concerns regarding potential selection bias.
  - Selection bias refers to inherent unobserved differences between the treatment group (those who participate in the study period) and the comparison group (those who do not), in absence of true experimental design.
  - Potential differences could cause divergence in usage trends over time, obfuscating savings.
- Guidehouse utilized future participants as a comparison group to mitigate the potential bias associated with the decision to participate – both study and future participants have made the decision to participate in the thermostat rebate program, but not at the same time.
  - Guidehouse acknowledged the potential for selection bias related to the timing of participation – i.e. the decision to participate in 2017/2018, vs after October 2018.
- The evaluators noted that the only way to fully mitigate this issue is to use true experimental design – e.g. RCT or RED.
  - This pathway was ruled out by Stakeholders, due to program design, time, and budget considerations. An RCT or RED is firstly a program design decision; no ComEd thermostat programs are currently structured this way.
  - In absence of true experimental design, using a comparison group is the generally accepted next best evaluation method for estimating savings (e.g. in Uniform Methods Project Chapter 8).
- To address stakeholder concerns, we adjusted the regression results for potential selection bias. More details are available in the next section.

Results Overview

- On average, study participants receiving an advanced thermostat rebate saved energy.
  – Based on study participants who are enrolled in the HER program
- These savings estimates result directly from the regression analysis. The analysis team made further adjustments that were not able to be directly incorporated into the regression model due to data constraints. More details are available in the next section.
- Savings are concentrated during daytime hours, when customers are likely to be away from home.
- Consumption appeared to increase during non-daytime hours (5 PM – 9 AM) after the rebate of an advanced thermostat, which could indicate comfort takeback and/or cooling load shifting behavior. This could also indicate the presence of selection bias.
- Guidehouse was unable to identify a high-quality comparison group for study participants who are not enrolled in the HER program.
  – Recommendation: apply savings estimate for HER participants to all customers.

Savings for Advanced Thermostats (for HER participants)

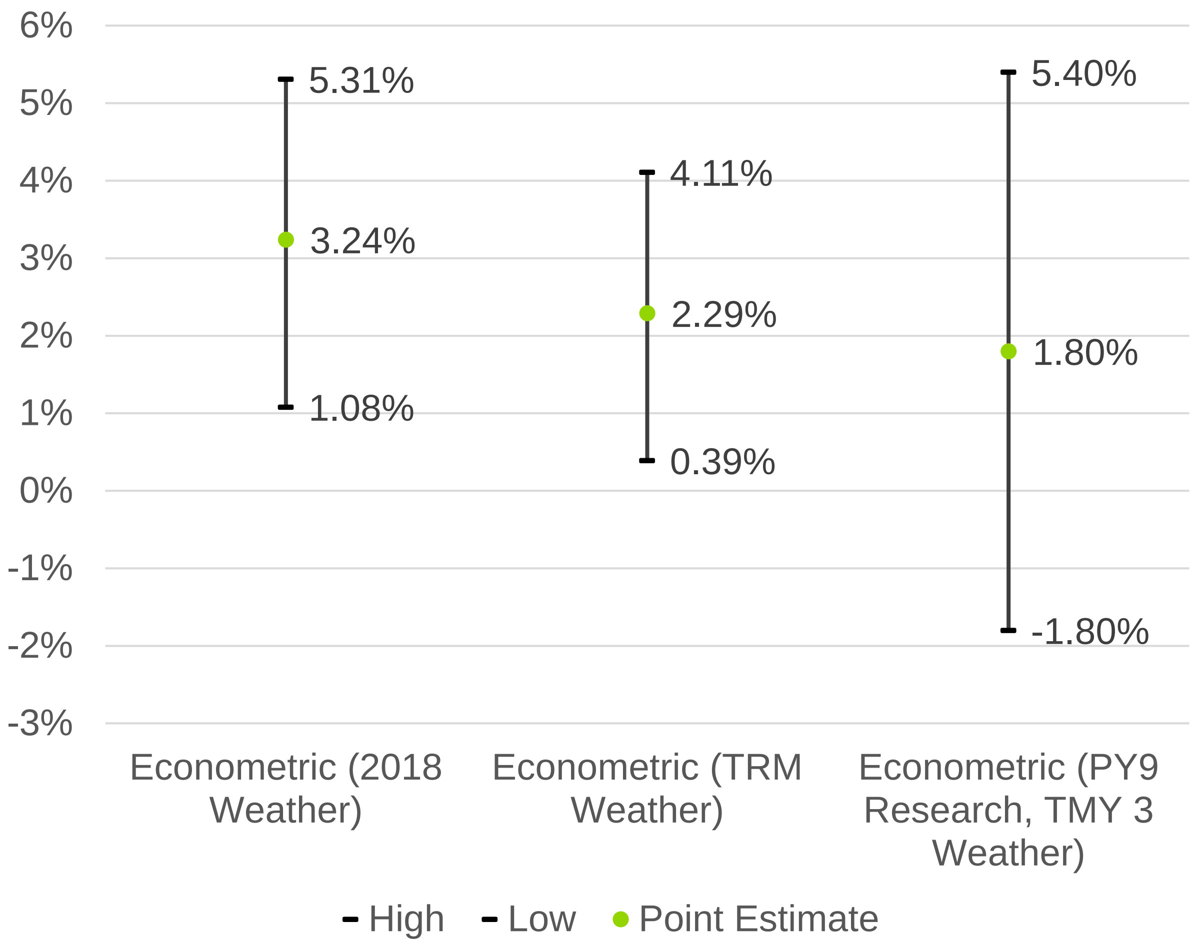
Time Period	Savings Value (kWh/day)	Savings Value (% of cooling load)
2018 Observed Weather		
Daily	0.40	3.24%
Day (9 AM – 5 PM)	0.57	10.48%
Night (5 PM – 9 AM)	-0.17	-2.48%

Weather Normalization

- The IL TRM v8 full load hours assumptions are based on a ComEd PY2 Central Air Conditioner (CAC) evaluation and are weather-normalized using TMY2 data.
- In general, the IL TRM specifies using the 30-year climate normal (1981-2010) for weather normalization.
- Guidehouse understands stakeholder concerns about the difference in more recent weather conditions being different than “normal” weather conditions estimated using weather from older years (e.g. 1981-2010).
- Conceptually, Guidehouse prefers to calculate percentage savings using cooling degree days (CDD) from the same time period as the cooling load is based on (since savings estimate / cooling load = percentage savings).
- Therefore, Guidehouse estimated the cooling reduction factor based on 2018 savings using 2018 weather data and used the aggregate thermostat telemetry data for cooling load (which is also based on 2018 weather).
- The estimated cooling load for calculating absolute savings via the IL TRM has not changed in v9; percentage savings are assumed to be the same for a different (lower, weather-normalized) cooling load.
  – A future change could be made to revise the IL TRM parameters for estimating cooling load (e.g., Full-Load Hours, Capacity) to better reflect more recent weather conditions and population.

Comparison to PY9 Analysis

- Guidehouse calculated weather normalized savings using the 30-year climate normal per the IL TRM v8, to allow for comparison with PY9 results.
- The econometric savings estimate Guidehouse found in this research is consistent with the research conducted in PY9.*
  – These savings estimates result directly from the regression analysis and do not include subsequent adjustments.
- In this research, Guidehouse recommends applying the savings estimate for HER customers to non-HER customers. In the PY9 study, the non-HER estimate was recommended, and the HER estimate was not found to be statistically different.
  – In both analyses, Guidehouse has recommended the estimate in which we had the most confidence, regardless of the HER status.

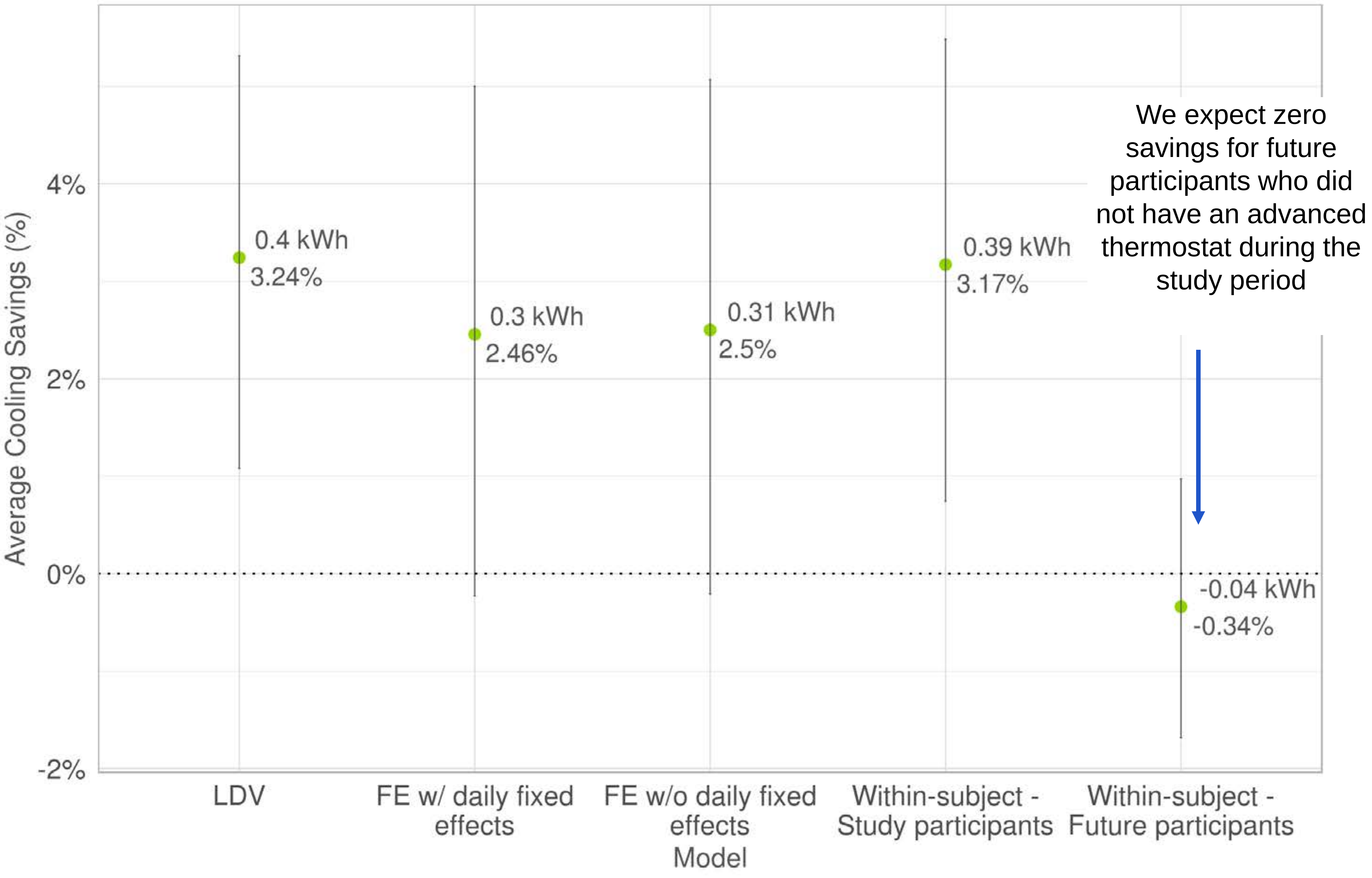


* ComEd Advanced Thermostat Evaluation Research Report (5 November 2018). Available at https://ilsag.s3.amazonaws.com/ComEd_Advanced_Thermostat_Evaluation_Research_Report_2018-11-02_Final.pdf

Model Specification

LDV and FE models did not produce statistically significantly different results.

- Guidehouse prefers the LDV model and results from this model are used in our recommendations to the IL TRM. However, we estimated several other models as a robustness check.
- All models are estimated using HER participants.
  - The comparison group for HER participants consists of all future participants who were enrolled in HER. No matching was employed.
- Savings are calculated using 2018 observed weather.
- The LDV and FE models generate results that are not statistically significantly different from each other.
- Guidehouse does not recommend the within-subjects model, but tested it based on stakeholder request. This result was also not statistically different from the others.

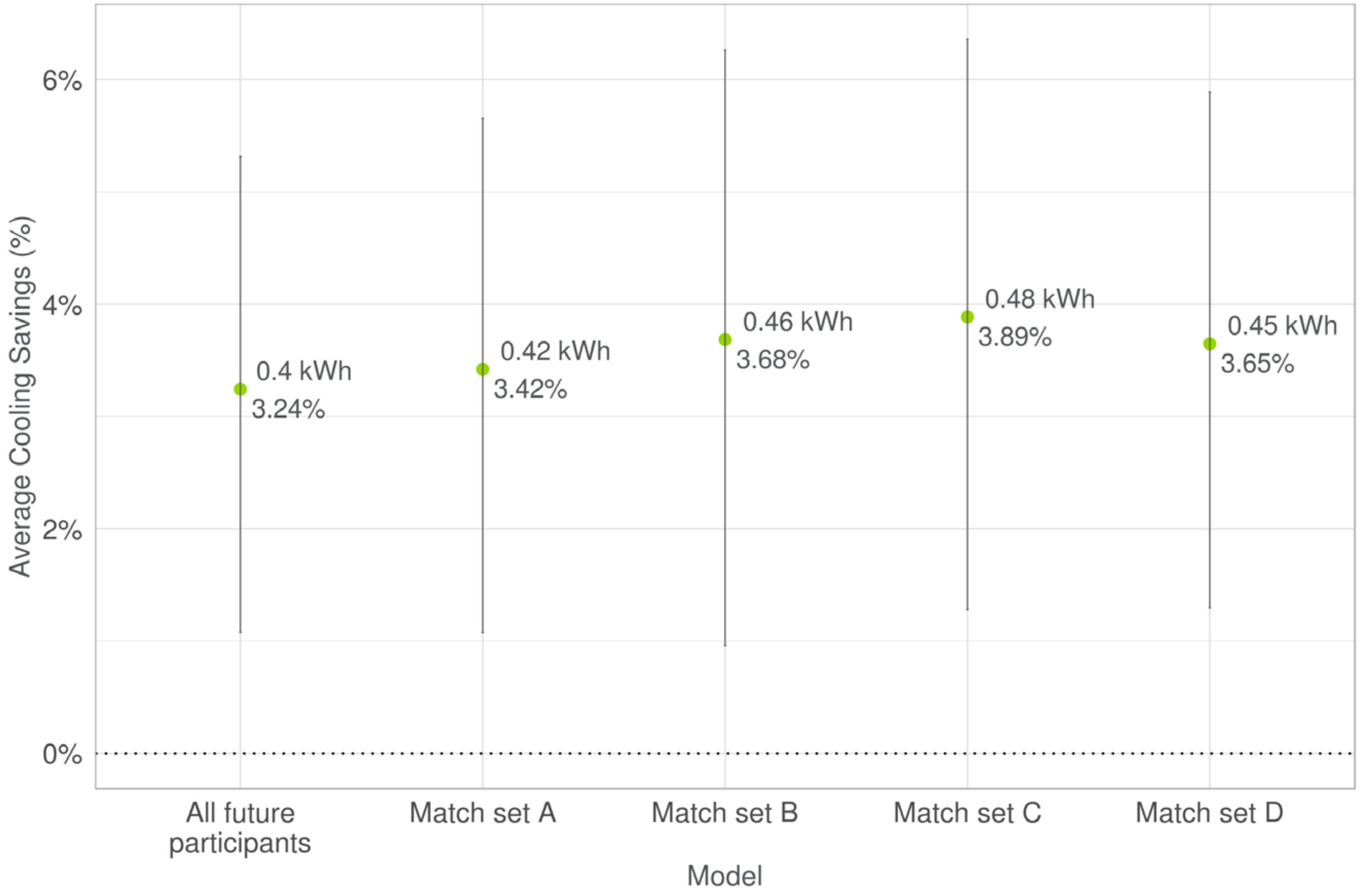


Guidehouse

Comparison Group

Results were not sensitive to the different comparison groups tested, indicating robustness.

- Although Guidehouse found that matching was not necessary to further refine our future participant comparison group, the team tested several matching schema for robustness.
- All models are estimated using HER participants.
- Match sets A, B, & C employ exact matching on customer characteristics, followed by Euclidean distance matching on hour buckets.
  - Set A: HER wave group
  - Set B: HER wave group + four PRIZM groups (household composition, lifestage, location, and wealth)
  - Set C: HER wave group + two PRIZM groups (lifestage and wealth)
- Match Set D does not employ any matching on customer characteristics. Matches are selected based on Euclidean distance over a 24-hr load shape for weekdays and weekends.
- PRIZM codes are defined in the Appendix.
- Savings are calculated using 2018 observed weather and the LDV model.



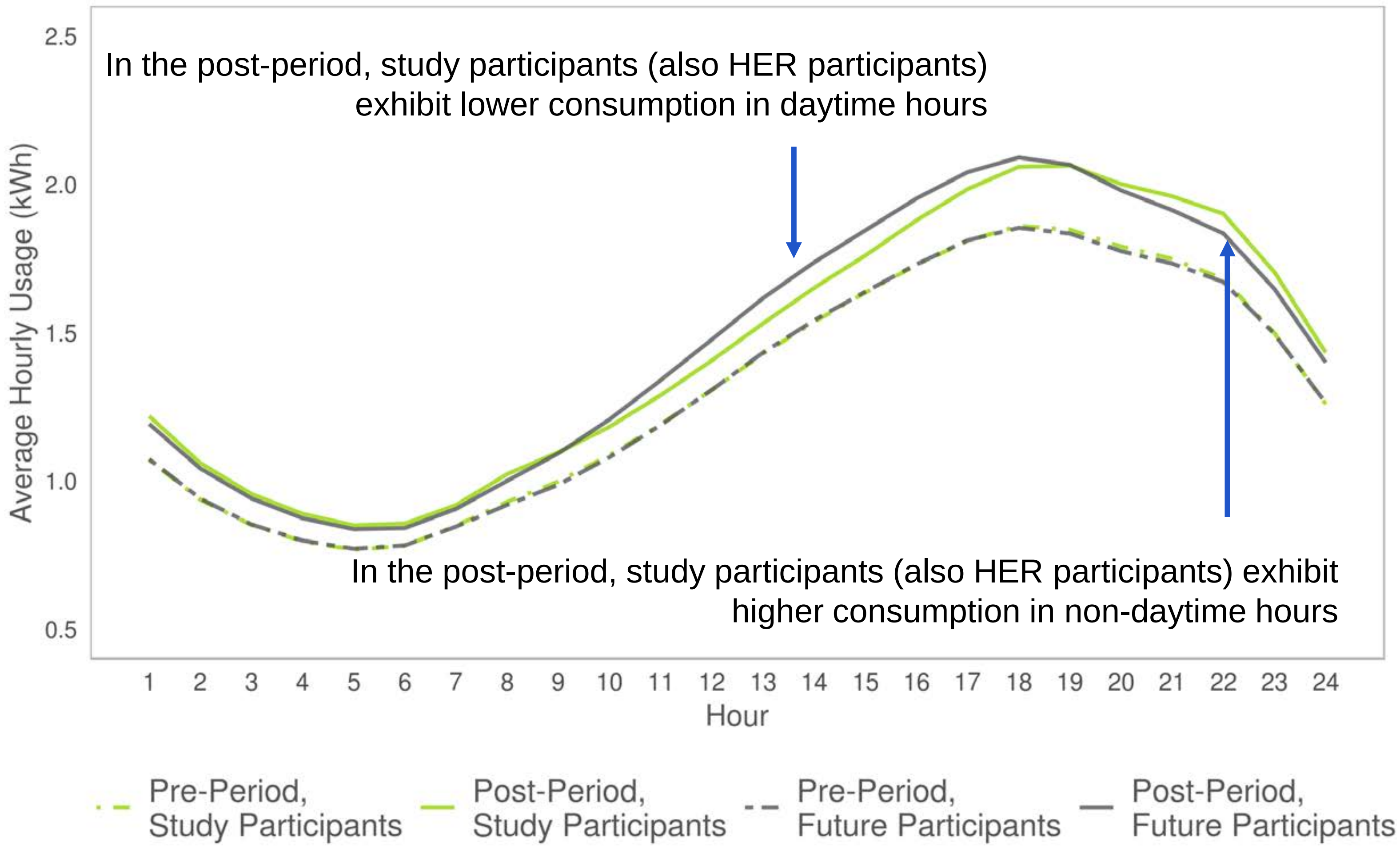
Guidehouse

Usage by Time of Day

Study participants show decreased consumption during daytime hours, and increased consumption in non-daytime hours.

- Study participants appear to generate energy savings during daytime hours, when they are most likely to be out of the home.
- Study participants exhibit high consumption in non-daytime hours, which may indicate “comfort takeback” during evening and overnight hours, or cooling load shifting away from daytime hours. This could also indicate the presence of selection bias.
- The comparison group for HER participants consists of all future participants who were enrolled in HER. No matching was employed.

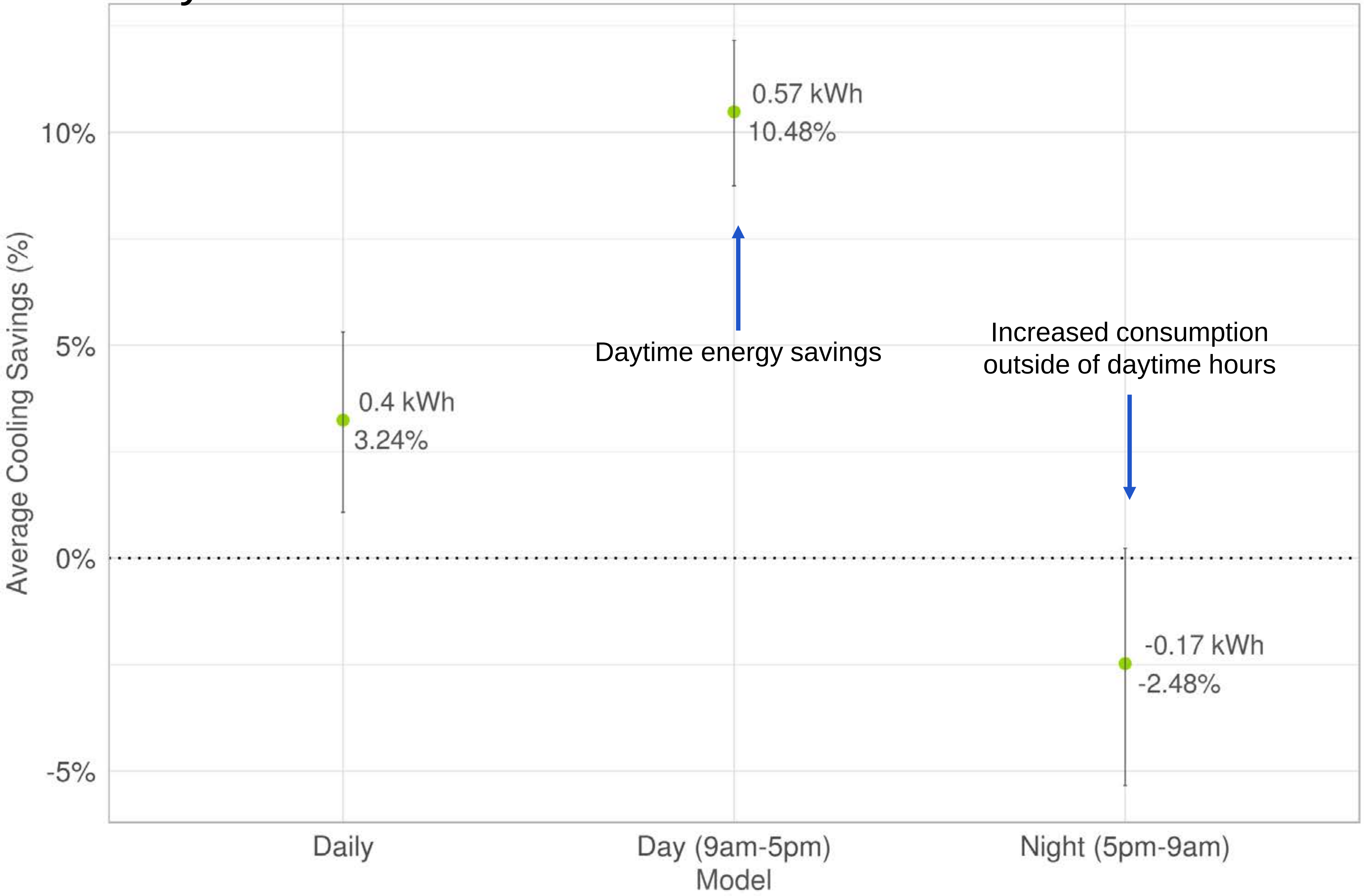
HER Participants Only



Savings by Time of Day

Savings are concentrated in daytime hours.

- Guidehouse estimated separate models for daytime (9 AM-5 PM) and nighttime (5 PM-9 AM). Daytime sayings were found to be statistically significant at 10.48% of cooling load. Nighttime savings were negative at -2.48%, but not statistically significant.
- All models are estimated using HER participants.
- The comparison group for HER participants consists of all future participants who were enrolled in HER. No matching was employed.
- Savings are calculated using 2018 observed weather and the LDV model.
- Percentage savings for the day and night models were estimated based on aggregate thermostat telemetry data.

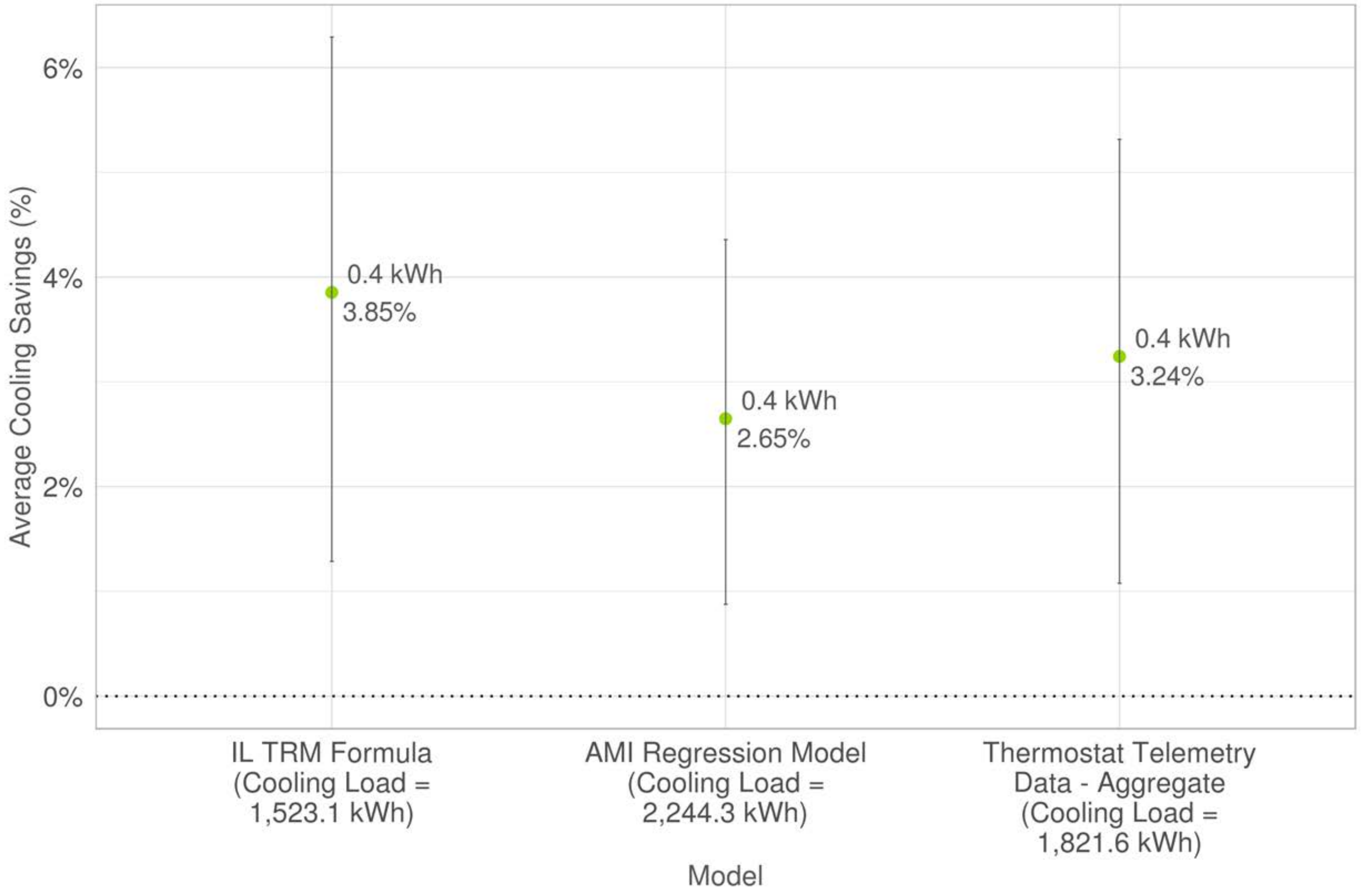


Guidehouse

Estimated Cooling Load

Percentage savings were not sensitive to different methods for estimating cooling load.

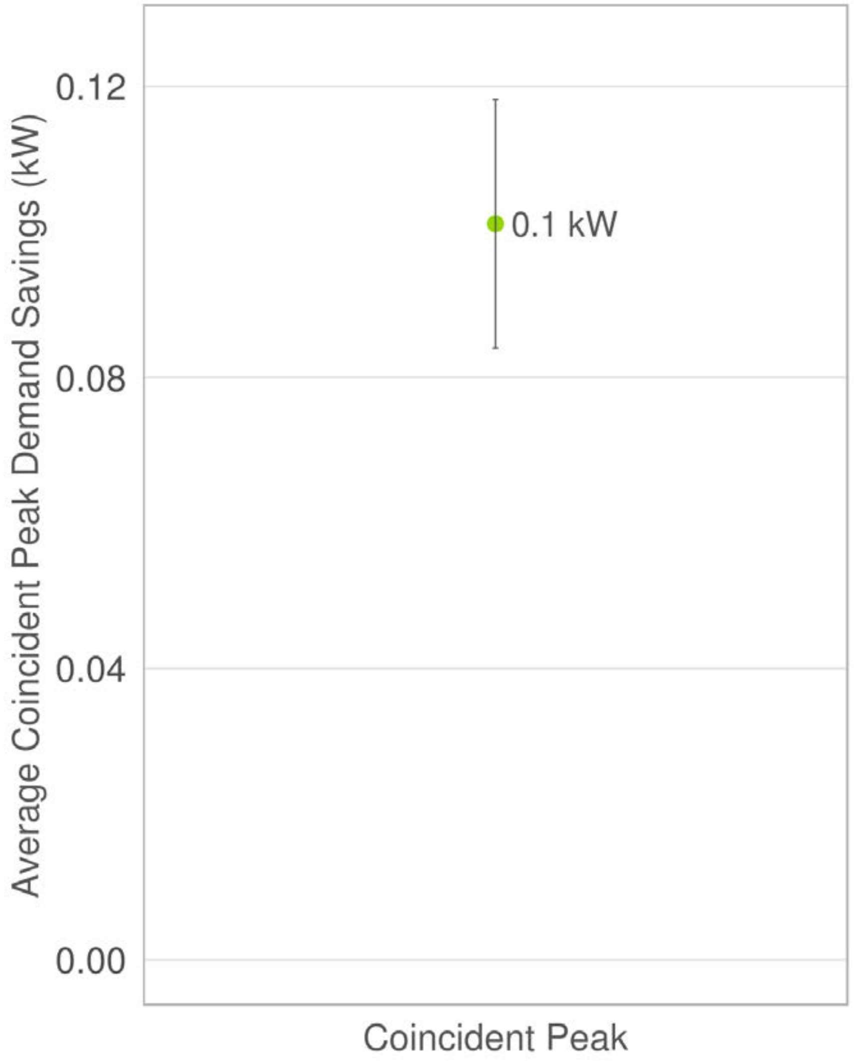
- Estimated savings per day (0.4 kWh) were multiplied by the number of days in the study period (153) and divided by the estimated seasonal cooling loads from the methods shown previously.
- Guidehouse used estimated cooling loads for HER study participants in the AMI regression model and the aggregate thermostat telemetry data.
- Per stakeholder feedback, Guidehouse recommends using the estimated cooling reduction via aggregate telemetry data (3.24%).
  – This value is not statistically different from the savings using other cooling load estimation methods.



Coincident Peak Demand Savings

- To estimate coincident peak demand savings, Guidehouse estimated the LDV regression model for the time period of 1-5 PM, June – August, non-holiday weekdays (per IL TRM definition)
- Guidehouse found average coincident peak demand savings for this time period of **0.101 kW +/- 0.017 kW (90% confidence interval)**
- Based on estimating cooling load via aggregated telemetry data, these savings correspond to 10.4% of cooling demand for the period.

HER Participants Only



Estimated Savings: Post-Regression Adjustments

Guidehouse

Adjustment Overview

Some factors could not be directly implemented in the regression analysis, due to data limitations or the timing of this research. Guidehouse explored and applied the adjustments to estimated savings in the following order:

1. **Selection Bias:** Adjustment for trends in base- and cooling-load of study participants
2. **% AC:** Study participants who did not have AC connected to their thermostat (i.e., did not generate any cooling savings)
3. **In-Service Rate:** Study participants who installed their thermostat during or after the study period (i.e., generated partial or no cooling savings)
4. **TO:** Reflects the wider availability of TO algorithms (i.e., Seasonal Savings and eco+) starting in 2020, after the study period, and expected going forward

Selection Bias (1/3)

Issue: Stakeholders raised concerns of selection bias, changes in energy usage unrelated to the installation of the smart thermostat that would not be accounted for via the comparison group or the regression model.

Findings

- Guidehouse reviewed a California (CA) study* referenced by Google. A key difference between the CA study and Guidehouse's study is that the CA study used non-participants as a comparison group (rather than future participants). A recommendation of the CA study is that future participants should be used instead. The CA study made three adjustments for selection bias summarized in the table below.

Adjustment Description	Applicability to Guidehouse's IL study
"Savings estimates are adjusted upward to account for the prevalence of smart thermostats among the comparison group." (pg. 45)	The CA study used non-participants rather than future participants as the comparison group. Guidehouse believe it is reasonable to assume that no future participants used as the comparison group in our study had advanced thermostats during our study period (1-10 months before they got a rebate).
Savings estimates are adjusted downward to account for customers who do not demonstrate cooling.	The CA study estimates site-level models which our method does not, thus we do not have data to conclude which sites demonstrate cooling. However, we believe this adjustment is more important for CA's statewide study than our IL work due to the broader geography covered. We think it is reasonable to assume that customers throughout ComEd's territory have some cooling needs. Note that to the extent this is not accounted for, our estimate would be overestimate savings (as this is a downward adjustment to savings).
"An adjustment is applied to cooling…savings estimates that removes the estimated differential trend in baseload…This adjustment attributes all of the change in baseload consumption to customer self-selection and assumes that electric cooling…consumption experience the same overall percentage trend, unrelated to the [smart thermostat], seen in the baseline." (pg. 44-45)	Guidehouse considered this adjustment given our methodology and believes the equivalent would be to only consider the savings estimate to come from the terms in our model that interact treatment with CDD. The terms with treatment that are not interacted with CDD are theoretically capturing the baseload shift, while the treatment terms interacted with CDD capture the cooling load shift. Guidehouse also explored an additional adjustment, applying the same trend in baseload to cooling load. This adjustment is discussed further on the next slides.

* Impact Evaluation of Smart Thermostats. Residential Sector – Program Year 2018. (16 April 2020). Prepared by DNV GL. Available at http://www.calmac.org/publications/CPUC_Group_A_Report_Smart_Thermostat_PY_2018_CALMAC.pdf

Selection Bias (2/3)

Framework to adjust for differential trends

- Guidehouse recognizes that surveys have shown that advanced thermostat installers tend to make other changes in their home when installing an advanced thermostat. These other actions can cause usage to trend apart even in the absence of installing an advanced thermostat.
  - The CA study found that adding an electric vehicle and using an additional refrigerator were commonly reported changes.
  - In the ComEd participant survey, respondents indicated changes that could increase and decrease usage. The most reported change was window replacement. Since this is not a rebated measure for ComEd, this change would decrease usage and, to the extent it occurred contemporaneously with the advanced thermostat rebate, would inflate savings.* Guidehouse also saw changes that could increase usage (for example occupancy changes and electric vehicles were reported).
- Guidehouse expects these changes could increase or decrease either baseload usage, HVAC usage, or both. For example, having a baby might cause a customer to use more cooling to keep the home more comfortable (HVAC change) and to increase use of clothes washers and dryers (baseload change).
- Some thermostat savings or spillover (increase or decrease in usage) could be captured by the baseload terms of our model. This would be an example of thermostat-related behavior change, not selection bias.
- Guidehouse acknowledges that the adjustment made in the CA study is a blunt instrument to account for differential trends. It assumes that all changes in baseload are due to selection bias. Furthermore, it assumes that this differential trend is the same percentage of cooling load.
- Guidehouse asserts that the regression model controls for additional sources of variation not captured by a simple difference of post-rebate load shapes (such as demographics) and therefore should be the basis for the adjustment capturing differential trends in baseload. This same rationale informs the use of regression analysis to estimate savings, rather than calculating a simple difference in usage.

* HVAC changes were also very common, although these are more likely to be removed from our study by our screening for participation in other ComEd energy efficiency measures. To the extent that some customers make HVAC changes without going through a ComEd program this could also inflate savings.

Selection Bias (3/3)

Adjustments to baseload and cooling load

- Removing the baseload terms from our savings estimate led to an increase of 0.10 kWh per account per day (from 0.40 to 0.50).
- Guidehouse estimated the selection-attributed baseload increase (0.1 kWh / day) as a percentage of participant baseload in the post period, 0.46%.
- Guidehouse then applied the same percentage trend to the estimated cooling load, i.e., assuming that the increase in cooling load offset achieved savings. Therefore the cooling savings should be increased by 0.46% of cooling load, or 0.08 kWh.
- The full selection-adjustment increased estimated savings from 3.24% to 4.45%.

Recommendation

- Stakeholders should consider whether these adjustments are precise enough to be acceptable for the purposes of the IL TRM. It is likely that the evaluation community will continue to try to refine adjustments of this type.
- Guidehouse has concerns about the accuracy of this adjustment but is providing this information in response to stakeholder requests.
- Given this, Guidehouse shows the percentage AC, ISR, and TO adjustment applied to both the 3.24% and 4.45% values, i.e., before and after this adjustment.

%AC

$$\Delta kWh_{cool} = \%AC \times \frac{FLH \times Capacity}{SEER \times 1000} \times Cooling\_Reduction \times Eff\_ISR$$

Issue

- Google identified study participants (10%) that did not have connected AC, based on thermostat wiring configuration.
- Suggests adjustment to Cooling Reduction percentage and the assumed percentage of participants that have central AC

Findings

- In the IL TRM, %AC is determined for each participant as*:

Thermostat control of air conditioning?	%AC
Yes	100%
No	0%
Unknown (AC-targeted program)	99%
Unknown (general program)	82.5%

- Guidehouse reviewed ComEd tracking data, which includes HVAC type for all programs through which advanced thermostats are rebated:
  - Tracking data indicates that 98% of customers have central AC and 1% have a heat pump (both provide cooling). Indicating 1% do not have cooling.
  - HVAC type is mostly self-reported via the Appliance Rebate Program. Other programs are direct install and these are contractor reported.
- Since identification of AC for evaluation is based on tracking data, savings would be claimed for participants, even if 10% did not actually have AC (as presented by Google).

Recommendations

- Adjust Cooling_Reduction for the percentage of customers with cooling, based on program tracking data – 99%
- This adjustment is based on practical considerations:
  - Google and ecobee are unable to share AC information for specific, individual thermostats (i.e., they cannot be removed from analysis)
  - Uncertainty in two factors offset:
    - A higher estimate of %AC, based on tracking data.
    - A lower estimate of Cooling_Reduction, because the actual percentage of customers with AC is inherent to the econometric analysis.
- Adjust the IL TRM cooling reduction factor for percentage of study participants with AC based on tracking data:
  - Non-"selection-adjusted" savings: 3.27**%**.
  - "Selection-adjusted" savings: 4.49%

* When AC information are recorded in the tracking data, %AC values corresponding to Yes/No are used. When AC information is missing from the tracking data, the applicable value of "unknown" is used.

In-Service Rate (1/2)

$$\Delta kWh_{cool} = \%AC \times \frac{FLH \times Capacity}{SEER \times 1000} \times Cooling\_Reduction \times Eff\_ISR$$

Issue

- Google identified study participants that installed their thermostat during or after the study post-period (May 2018 or later)
- Suggests that cooling reduction should be adjusted to reflect only thermostats that were installed

Findings

- Google provided statistics* on thermostat installs for our study participants and Guidehouse used this data to develop an adjusted cooling reduction value and effective ISR. Important assumptions:
  - 2.60% of all participants had an invalid serial number – Guidehouse assumed these devices installed at the same rate as valid serial numbers
  - 10.62% of participants with valid serial numbers could not be identified in Google's database. After discussion with stakeholders and VEIC, Guidehouse assumed that 3.25% of these devices were never installed, the remainder represent typos (i.e. installed at same rates as other devices, but serial number was misreported)

Description	Percent of Participants
Participants who generated ***no savings***; includes: • Installed outside of Illinois, 6.75% • Participants assumed not to install at all, 3.25% • Participants who activated after the study post-period, 4.33%	14.33%
Participants who generated ***partial savings***, includes: • Participants who installed during the study post-period Guidehouse estimated partial savings as the weighted-average savings for these participants based on when they installed throughout the season	3.61%

* ecobee was able to provide a similar set of statistics for participants with ecobee devices. However, 65% of serial numbers reported in ComEd tracking data were not valid ecobee serial numbers; specifically, many serial numbers were truncated, with the last several digits replaced by zeroes. As a result, Guidehouse used the available data as a robustness check and verified similar percentages as determined from Google's data; however, we did not update these numbers due to the large amount of invalid or misreported serial numbers for ecobee devices.

In-Service Rate (2/2)

$$\Delta kWh_{cool} = \%AC \times \frac{FLH \times Capacity}{SEER \times 1000} \times Cooling\_Reduction \times Eff\_ISR$$

Recommendations

- Adjust the IL TRM cooling reduction factor for percentage of study participants who did not install, or who installed partway through the season:
  - Non-”selection-adjusted” savings: 3.91%.
  - “Selection-adjusted” savings: 5.38%
- VEIC recommended an updated ISR value of 90% for non-direct install programs where not otherwise evaluated, based on Google activation data for customers who activate their device outside of Illinois (6.75%) and a percentage of customers assumed to never install (3.25%). For more details, see the Appendix.
  - The ISR for direct install programs will remain 100%.
- Of those participants who received a rebate between October 2017 and March 2018, Google observed activations up until August 2020 when data was provided, indicating that some customers will wait to install the device, while other may never install.

Thermostat Optimization (1/2)

Issue

- TO programs (i.e., Seasonal Savings and eco+) have recently been offered or expanded, which have changed savings achieved by advanced thermostats since our study period.

Findings

- Guidehouse utilized data from Google and ecobee, as well as past evaluation reports of TO programs:†,‡
  - Enrollment rates in TO programs for study participants in summer 2018 and currently for all Illinois devices.
  - Incremental savings (i.e., in addition to thermostat installation) for TO programs.*
- Guidehouse estimated a cooling reduction percentage, combining the results of this study and expected savings from TO**:

Combined Savings = *Savings from the econometric analysis, discounted for enrollment in any TO programs in summer 2018* + *Incremental savings from future enrollment in applicable TO programs, weighted by manufacturer market share, and enrollment in each program.*

* Based on feedback from VEIC, incremental savings associated with Seasonal Savings were applied to all Google Nest and ecobee devices. This centered on the fact that a full, third-party report was not available to verify eco+ savings.

** The absolute savings from advanced thermostats and TO are additive. Guidehouse has percentage savings to work from and therefore made baseline adjustments to the TO percentages. These calculations are available upon request.

† ComEd CY2018 Nest Seasonal Savings Heating Season Impact Evaluation Report. Available at: https://s3.amazonaws.com/ilsag/ComEd-CY2018-Nest-Seasonal-Savings-Heating-Season-Impact-Evaluation-Report-2019-03-11-Final.pdf

‡ ComEd CY2018 Seasonal Savings Cooling Season Impact Evaluation Report. Available at: https://s3.amazonaws.com/ilsag/ComEd_Seasonal_Savings_CY2018_Cooling_Season_Impact_Evaluation_Report_2018-04-08_Final.pdf

Thermostat Optimization (2/2)

Incremental Cooling Savings from TO*

Description	Incremental Cooling Savings (Percent of Cooling Load)
Nest Seasonal Savings per Treated Device in 2018; used to discount savings estimated for the study period	2.25%**
Nest Seasonal Savings per treated device looking forward; used to estimate additional savings in the future	6.32%†

Recommendation

- Adjust the IL TRM cooling reduction factor for changes in TO:
  - Non-“selection-adjusted” savings: 6.36%
  - “Selection-adjusted” savings: 7.79%

* From ComEd CY2018 Seasonal Savings Cooling Season Impact Evaluation Report. Available at: https://s3.amazonaws.com/ilsag/ComEd_Seasonal_Savings_CY2018_Cooling_Season_Impact_Evaluation_Report_2018-04-08_Final.pdf

** 1.55% per intent to treat (ITT) device; with an opt-in rate of 69%, this is 2.25% per treated device

† 2.66% per ITT device; with an opt-in rate of 67%, this is 3.97% per treated device. 1.46% persistence per ITT device; with an opt-in rate of 62% from the previous year; this is 2.35% per treated device. Savings = 3.97% + 2.35%.

Coincident Peak Demand Savings (adjusted)

- Guidehouse estimated the LDV regression model for the time period of 1-5 PM on non-holiday weekdays from June – August, (per IL TRM definition) to estimate coincident peak demand savings.
- Guidehouse applied similar adjustments to coincident peak demand savings for % AC, selection, ISR, and TO*

	Estimated Savings, after all adjustments (%)
Non-selection-adjusted	15.70%
Selection-adjusted	16.41%

* For TO, Guidehouse used estimates of demand savings (3.49% per treated device in 2018, 9.2% per treated device moving forward) from a recent Seasonal Savings evaluation, for the period of 2-6 PM, non-holiday weekdays (June 22 to Sept 20, 2018). Although not the same period as defined in the IL TRM, Guidehouse used these results as the best available estimates of the impact of TO in the future. See ComEd CY2018 Seasonal Savings Cooling Season Impact Evaluation Report. Available at https://s3.amazonaws.com/ilsag/ComEd_Seasonal_Savings_CY2018_Cooling_Season_Impact_Evaluation_Report_2018-04-08_Final.pdf

Adjustments Summary

The following table summarizes the post-regression adjustments to savings estimates.

Result	Energy Savings (Percent of Cooling Load)		Coincident Peak Demand Savings (Percent of Cooling Load)	
	Non-Selection Adjusted	Selection Adjusted	Non-Selection Adjusted	Selection Adjusted
Regression Model	3.24%	-	10.37%	-
Selection Bias	3.24%	4.45%	10.37%	10.99%
% AC	3.27%	4.49%	10.47%	11.10%
ISR	3.91%	5.38%	12.48%	13.22%
TO	6.36%	7.79%	15.70%	16.41%

In addition, the corresponding changes to the IL TRM include:

- Eff_ISR – 100% (Direct Install), 90% (other programs if not evaluated), for estimating cooling savings.
- %AC – Unchanged from IL TRM v8

ENERGY STAR Analysis Results

Overview

- The objectives of the ENERGY STAR analysis were:
  - To estimate a range of savings associated with different assumptions about baseline behavior (i.e., ***before installation*** of an advanced thermostat)
  - Identify the relative importance of different assumptions that affect estimated savings using the ENERGY STAR algorithm
- Guidehouse developed adjustments to the ENERGY STAR method, focusing on:
  - Baseline comfort temperature – The ENERGY STAR method assumes that a customer would use a constant temperature set point in absence of an advanced thermostat, equivalent to the 10^{th} percentile of their post-installation temperature history.
  - Setback behavior – The ENERGY STAR method assumes a customer would not make changes to their chosen temperature set point in absence of an advanced thermostat.
- Guidehouse estimated a range of runtime savings based on survey responses regarding how customers used their thermostat before advanced thermostat installation, described on the next slides.
  - Assumptions used were selected to provide context on the range of savings that could be expected, as well as the sensitivity of savings to different assumptions (e.g. the effect of a setback on savings).
- Additional details on methodology can be found in the Appendix

Adjustments to the ENERGY STAR Method

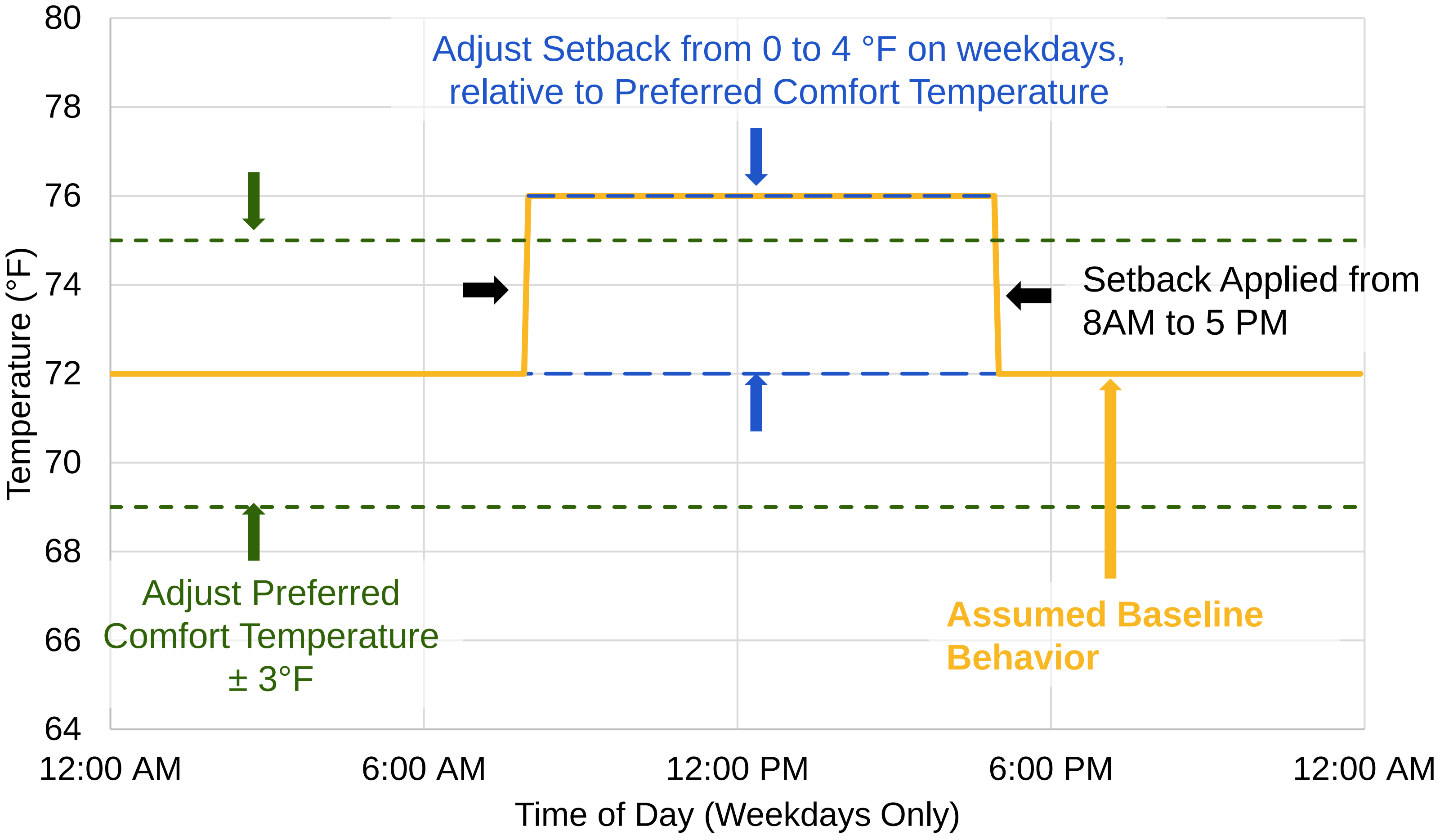
Guidehouse ran the adjusted algorithm on a sample of anonymized telemetry data provided by Google for HER and non-HER customers.

- **Baseline comfort temperature –** edit ENERGY STAR algorithm to estimate an adjusted baseline comfort temperature
  - Current ENERGY STAR algorithm: Assumes a ***constant (i.e., all the time)*** baseline comfort temperature, which is the 10th percentile of hourly indoor temperature history
  - Adjusted Baseline:
    - Only include hours with runtime (reduce free cooling or free heating)
    - Only include hours where temperature is within 1 degree of setpoint (approximately steady state)
    - The baseline is the minimum of the actual indoor temperature and the preferred comfort temperature to avoid producing unrealistic “negative savings”
    - Test using the 10th, 15th, and 20th percentiles as the selection criteria for baseline comfort temperature
    - Estimate sensitivity to changes of the preferred comfort temperature (**+/- 3°F**). Provides context around the sensitivity of savings estimates to the assumed preferred comfort temperature ***before installation***
- **Setback behavior –** edit ENERGY STAR algorithm to account for setback behavior
  - Current ENERGY STAR algorithm: Assumes there is no setback behavior
  - Adjusted Algorithm: Estimate baseline runtime accounting for assumed setback behavior relative to the baseline comfort temperature
    - A range of baseline setpoint changes from ***0 to +4°F*** for the period during the day when no one is home, ***8 AM to 5 PM***
      - Note that 0°F means no setback and 4°F is the most aggressive setback tested
    - ***Do not apply a setback for other times of the day*** (i.e., during the evening when people are home and overnight)
    - Daytime setback is applied for ***weekdays only***
    - The evaluators explored available data to estimate ***what percentage of homes may use a setback***

Guidehouse

Adjustment Summary - Illustration

Parameters ***Before*** Installation of an Advanced Thermostat



- The adjustments to the ENERGY STAR method are illustrated for a single weekday, which shows the assumed baseline (indicated in yellow) that a person would follow in absence of an advance thermostat.
- The preferred comfort temperature in this example (72°F) was shifted up or down by 3°F (indicated in green), and setbacks between 0°F and 4°F were applied between 8 AM and 5 PM (indicated in blue).

Adjustment Summary

Limitations of Survey Data

- The explored adjustments were selected based on reviewing the ComEd participant* and general population surveys**
- Existing self-reported data on preferred temperatures does not provide sufficient information to fully characterize pre-installation behavior, such as:
  - Share of time the air conditioning system is turned off/not used, such as
    - Long absences
    - Vacations
    - Turning system off during the day when away
  - Share of time when individuals may override programmed thermostat settings
  - Distribution of preferred comfort temperatures before installation of an advanced thermostat
  - Distribution of programmed setbacks before installation of an advanced thermostat (e.g., no setback, moderate setback, or high setback)
  - Share of time when individuals are programming a setback into their thermostat (e.g., only on weekdays, from 8 AM to 5 PM)

* ComEd Advanced Thermostats Research 2018 Participant Survey Results. https://ilsag.s3.amazonaws.com/ComEd-Tstat-Participant-Survey-Results-Final-2020-01-21.pdf
** ComEd Smart Thermostat Customer Preference Study. https://ilsag.s3.amazonaws.com/ComEd_Thermostat_Customer_Preference_Study_Results_FINAL_2019-10-11.pdf

Thermostat Sample

- Participants are customers who received a rebate for an advanced thermostat after cooling season 2017 (on or after Oct 1, 2017) and before cooling season 2018 (on or before May 31, 2018)
  - This full group is essentially the same as the study participants for the econometric analysis (before data cleaning)
- Guidehouse received a sample of 12 months of device-level, post-installation telemetry data for 250 HER and 250 non-HER participants from Google (June 1, 2018 – May 31, 2019)
  - The ENERGY STAR algorithm estimates cooling savings based on core cooling days (days with at least 30 minutes of cooling and no heating demand).
- The ENERGY STAR algorithm filters devices based on insufficient data (e.g., missing day(s) or weather)
  - Guidehouse replaced one zip (60622) with a nearby zip (60638, Midway) to ensure weather data was available and maximize sample size*
- The ENERGY STAR algorithm also filters based on the runtime model parameters and savings outliers
  - Tau (“base” thermal demand) between 0 and 25
  - CVRMSE (quality of runtime model fit) less than 0.6
  - Percentage savings between 1st and 99th percentiles

Description	HER Participants	Non-HER Participants
Received	250	250
After Algorithm Data Checks	241	238
After Results Filtering (Depends on Scenario)	205-207	166-169

* Since data was available for only 500 total participants were available, Guidehouse used similar weather to ensure that participants were not dropped from the ENERGY STAR algorithm due to a lack of weather data.

Adjusted ENERGY STAR Analysis Results: Baseline Comfort Temperature

Guidehouse

Adjustment Summary

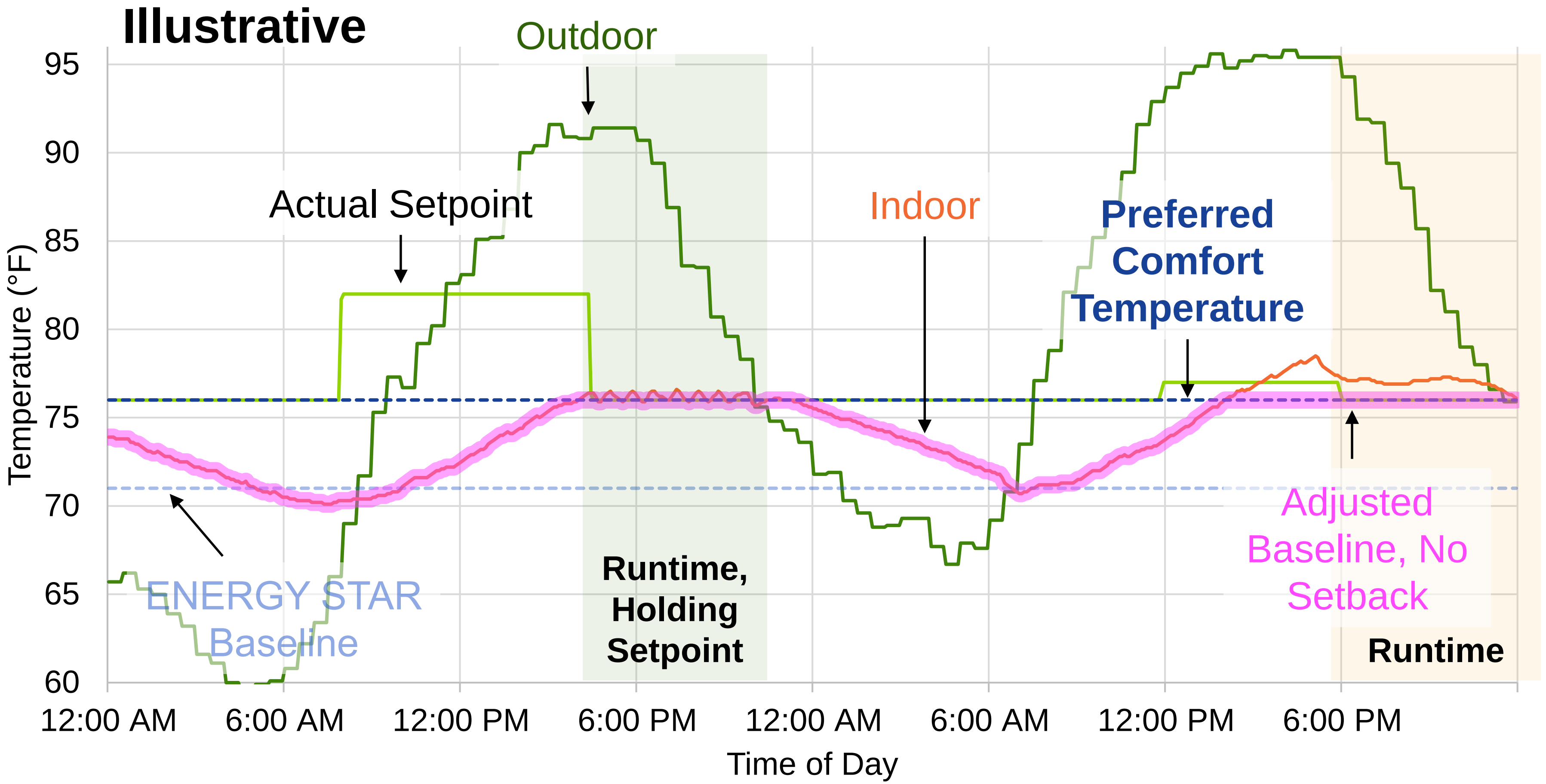
Adjusted Baseline, No Setback

The evaluators first explored adjusting the baseline only, with no setback.

- **Baseline comfort temperature –** edit ENERGY STAR algorithm to estimate an adjusted baseline comfort temperature
  - Current ENERGY STAR algorithm: Assumes a ***constant (i.e., all the time)*** baseline comfort temperature, which is the 10th percentile of hourly indoor temperature history
  - Adjusted Baseline:
    - Only include hours with runtime (reduce free cooling or free heating)
    - Only include hours where temperature is within 1 degree of setpoint (approximately steady state)
    - The baseline is the minimum of the actual indoor temperature and the preferred comfort temperature to avoid producing unrealistic “negative savings”
    - Test using the 15th, and 20th percentiles, in addition to the 10th percentile as the selection criteria for baseline comfort temperature
    - Estimate sensitivity to changes of the preferred comfort temperature (**+/- 3°F**). Provides context around the sensitivity of savings estimates to the assumed preferred comfort temperature ***before installation***

Adjusted Baseline, No Setback

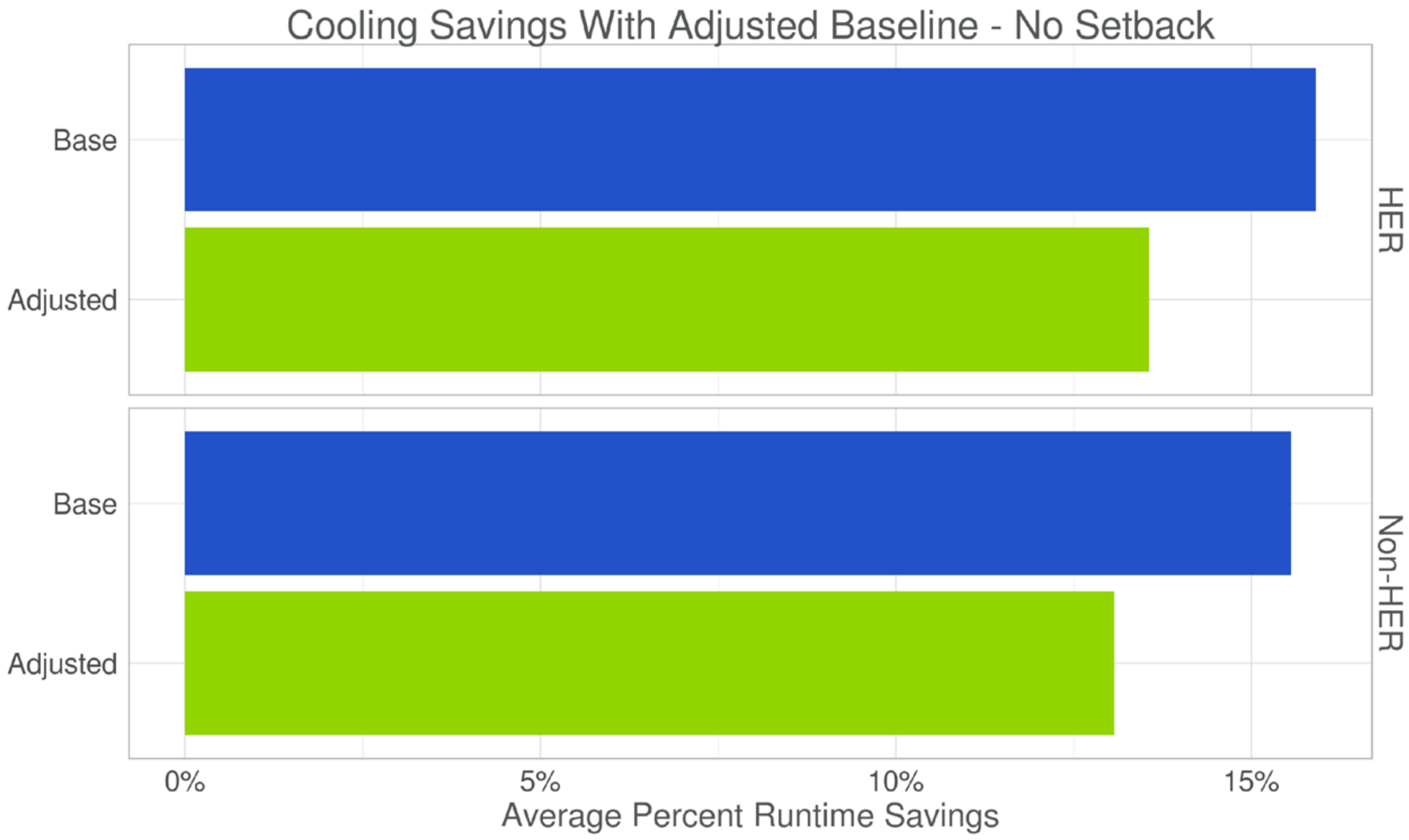
Illustration



- The ENERGY STAR Baseline (indicated in light blue) is selected as the 10^{th} percentile of all indoor temperatures observed.
- The adjusted preferred comfort temperature (in dark blue) is instead selected from hours where the system is holding the setpoint (shown by green shading).
- To avoid negative savings, the adjusted baseline (indicated in pink) is the minimum of the indoor (indicated in orange) and preferred comfort (indicated in dark blue) temperatures.

Adjusted Baseline, No Setback

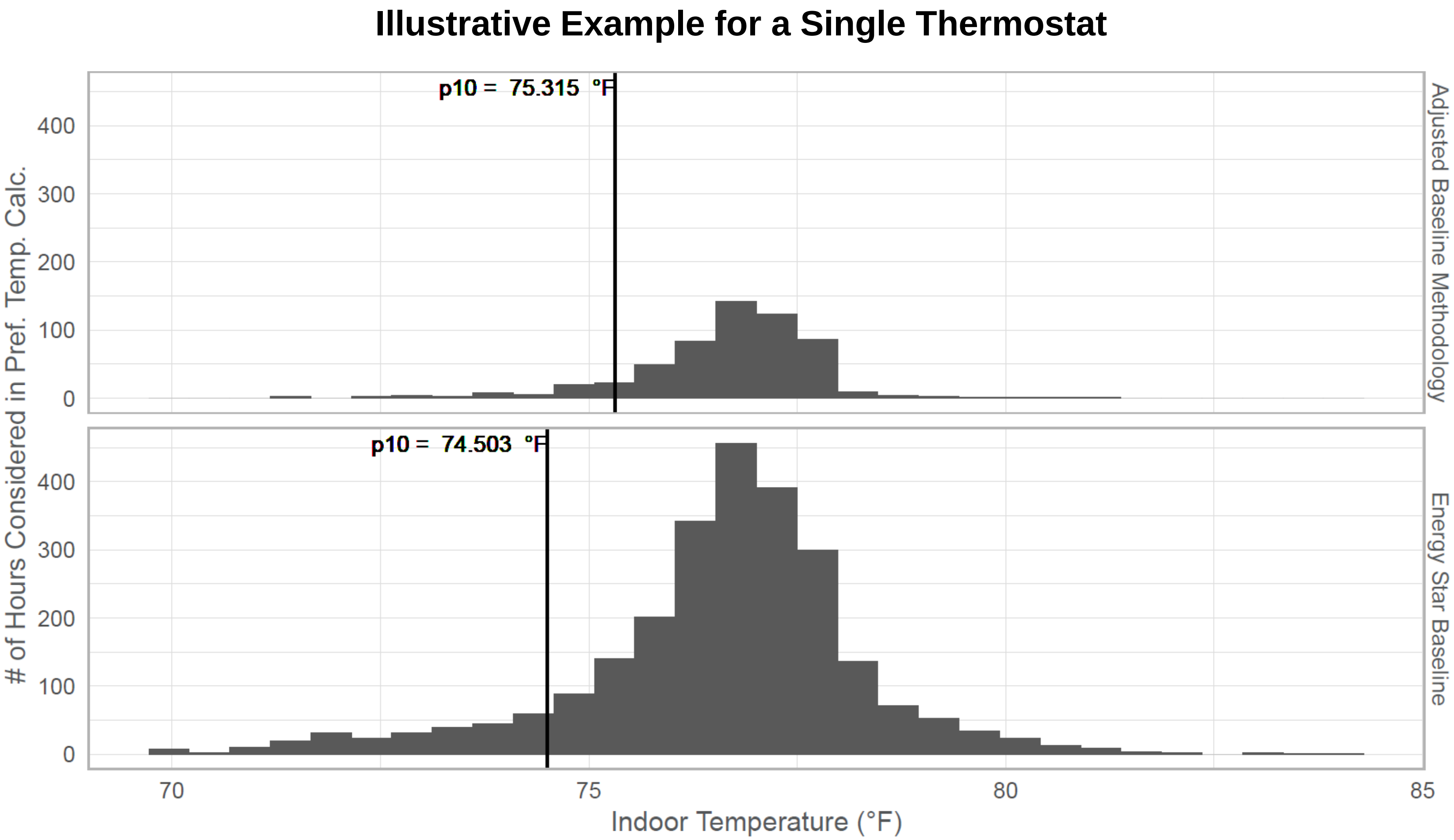
Savings Estimates



- The adjusted baseline temperature has a slight effect on runtime savings, approximately 2.5% lower than the base (unadjusted) ENERGY STAR result.
- Results are similar for HER and non-HER customers.

Adjusted Baseline, No Setback

Comfort Temperature

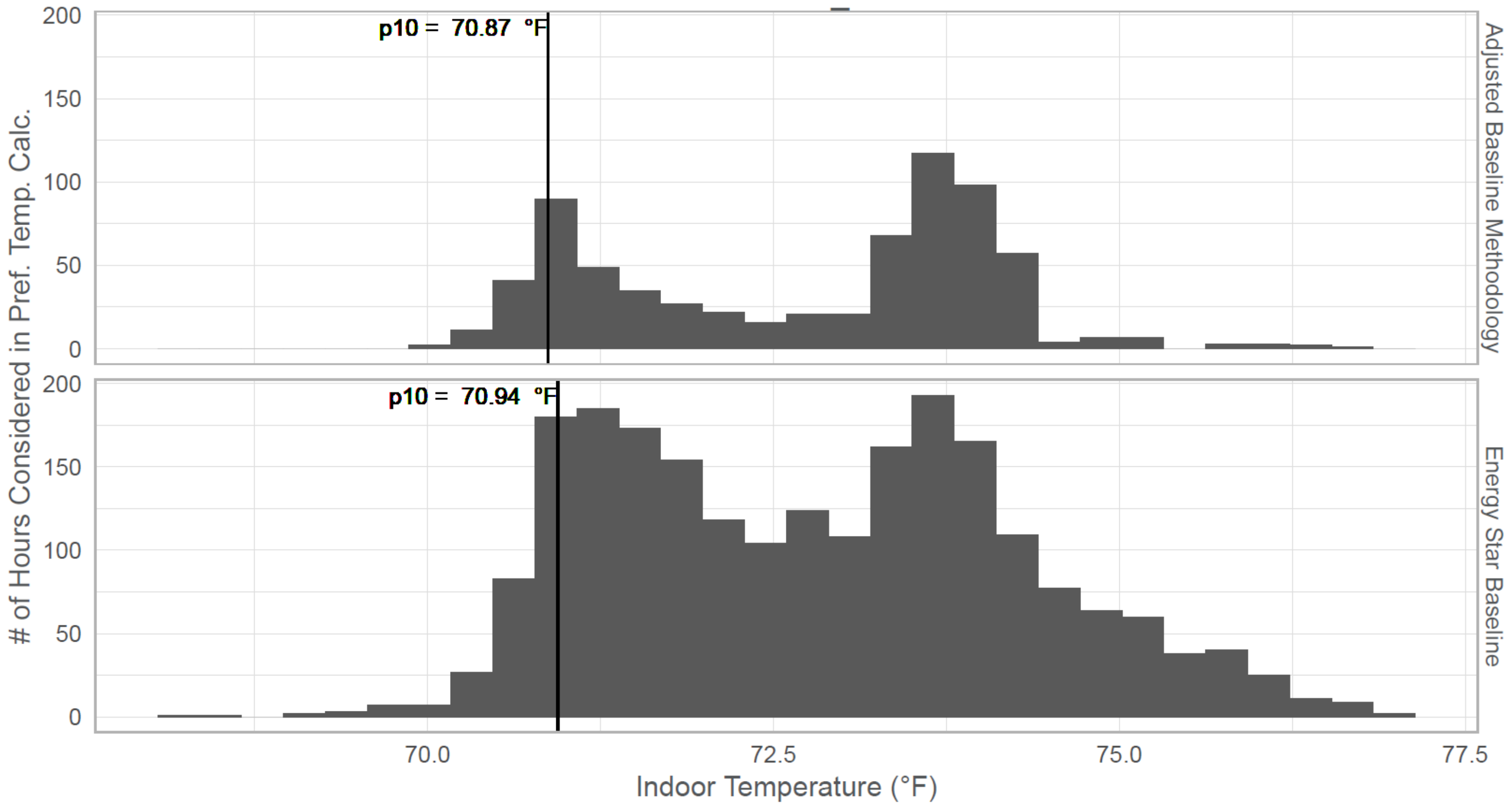


- This slide and the next slide show indoor temperature history for two example households, to show the variation in customer behavior.
- The top panel shows just hours included in the adjusted methodology (where the system is holding the setpoint), while the bottom panel shows all hours. In each panel, the vertical line shows the selected preferred comfort temperature selected by the algorithm.
- In the ENERGY STAR Algorithm, this temperature is used as a constant baseline from which savings are estimated. This constant baseline is sufficient for comparisons between devices. However, evaluated energy savings estimates require a more accurate understanding of the baseline to accurately estimate savings.
- The assumption of the 10th percentile may or may not accurately reflect actual baseline behavior.

Adjusted Baseline, No Setback

Comfort Temperature

Illustrative Example for a Single Thermostat



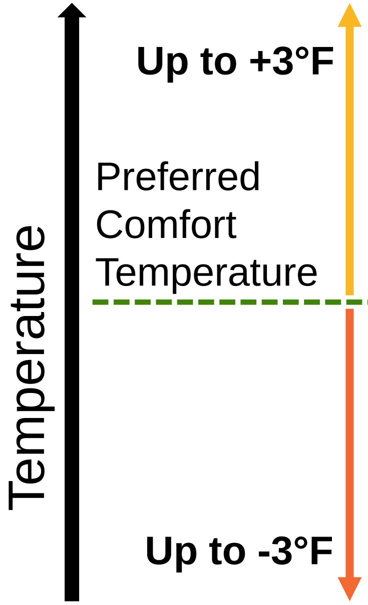
- This household shows a different distribution of temperatures, with two peaks representing different common temperatures. This suggests that the household may change its preferences and behavior based on different factors.
  - Possible explanations might include a daytime setback, or different preferences by season.
- The variation in customer behavior is a challenge for inferring baseline behavior – how a household would use a non-advanced thermostat.

Preferred Comfort Temperature

Parameters Before Installation

Guidehouse explored the sensitivity of savings estimates to the assumed preferred comfort temperature ***before installation.*** We tested sensitivity to changes of the preferred comfort temperature by **+/- 3°F.**

- Accounts for uncertainty in the current method of selecting the comfort temperature (i.e., the 10th percentile of indoor temperature history) and its representativeness of baseline behavior.
- Provides context for how an advanced thermostat may cause changes in a customer's preferred comfort temperature.
- Because the preferred temperature is assumed to be the baseline temperature, provides context for sensitivity of savings estimates to different baselines.



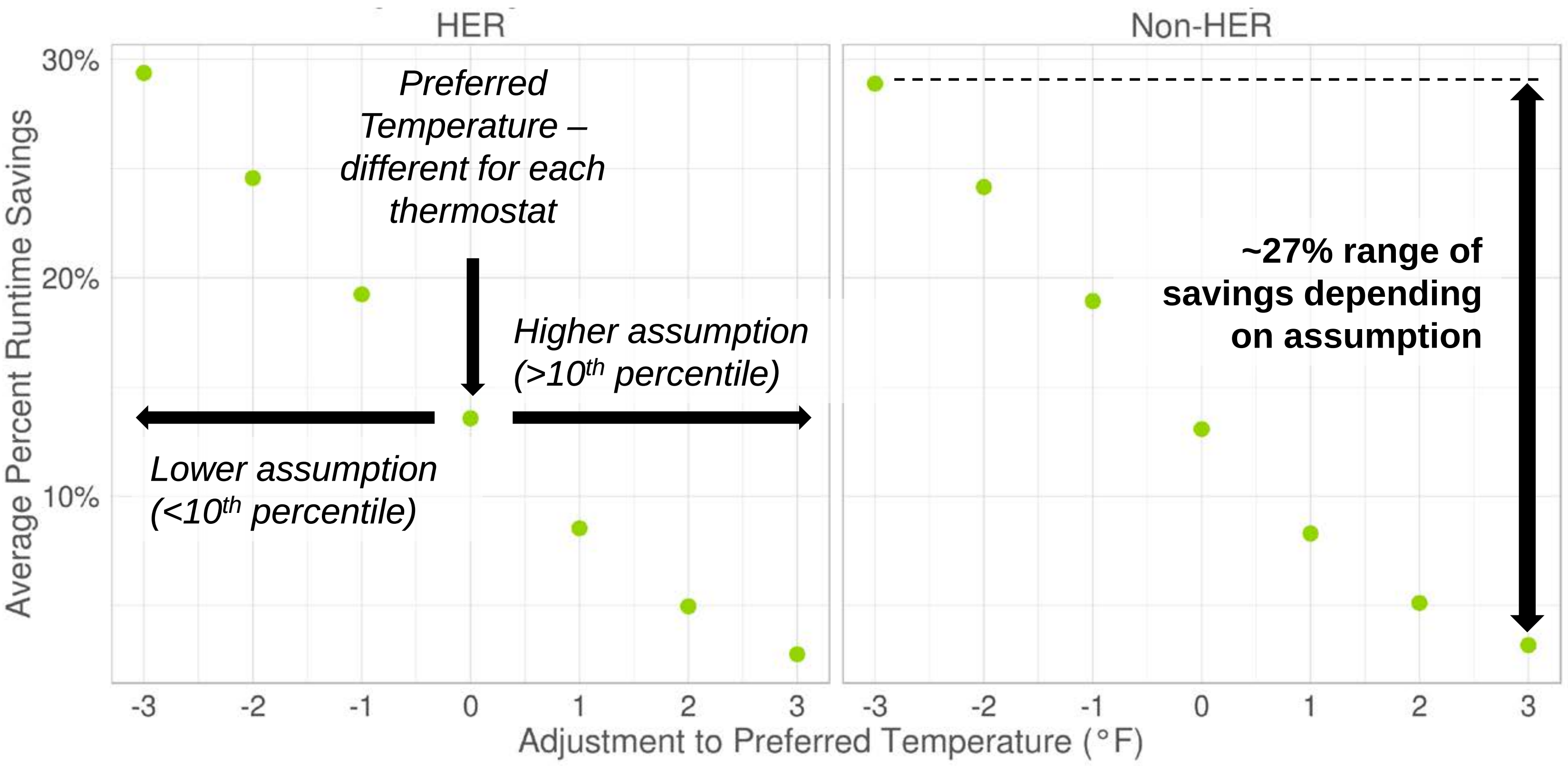
- An ***increase*** means the preferred comfort temperature *before* installation was higher than the 10th percentile of temperatures seen *after* installation.
- Acknowledges that customers may not have been setting their thermostat to the 10th percentile all the time (e.g., they may actually prefer a higher temperature).

- A ***decrease*** means the preferred comfort temperature *before* installation was lower than the 10th percentile of temperatures seen *after* installation.
- Acknowledges that the smart thermostat may cause customers to set higher (more efficient) temperatures.

Guidehouse

Preferred Comfort Temperature

Savings Estimates

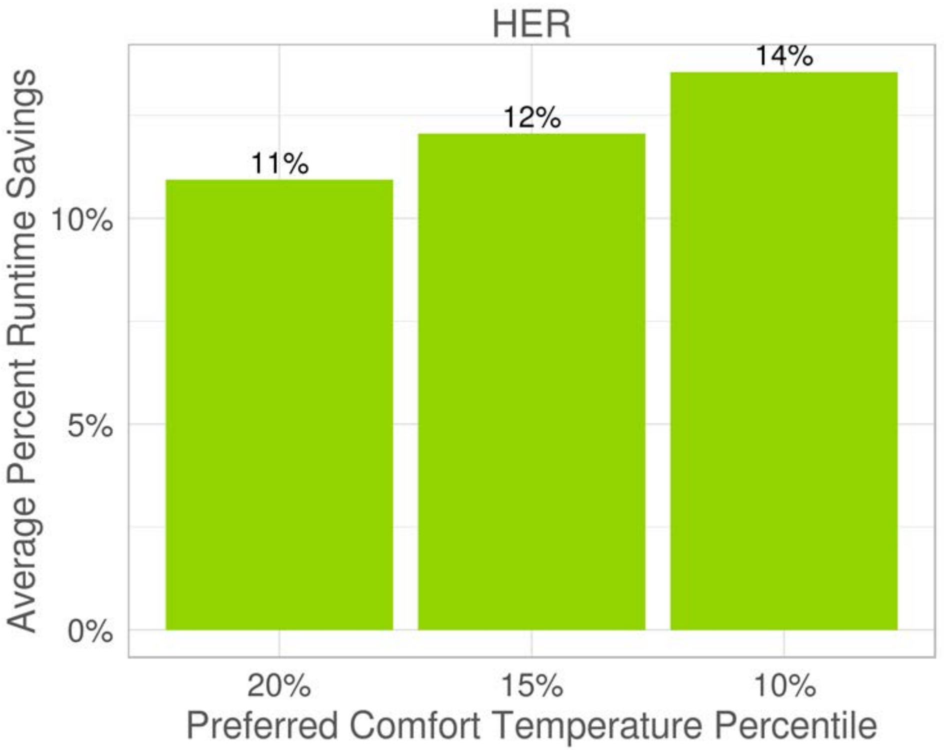


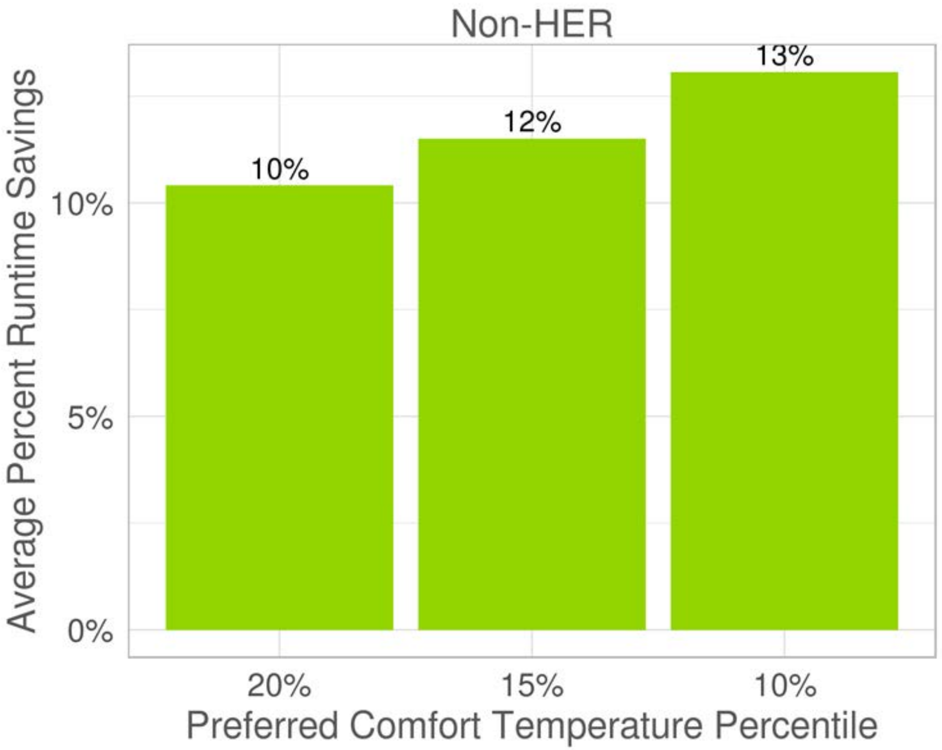
- Changing the assumed preferred comfort temperature by ± 3°F leads to estimated savings with a range of approximately 27%.
- Guidehouse selected this range primarily to explore the sensitivity of savings to the selection of preferred comfort temperature.
  - This sensitivity was selected symmetrically in response to stakeholder request to explore ways in which advanced thermostats may nudge customers towards more efficient set points.
  - The range also represents potential uncertainty in the accuracy of the 10th percentile in representing the baseline temperature profile used to estimate savings.
  - The range selected does not necessarily represent accuracy of these savings estimates.
- Stakeholders expressed that it is unlikely that a customer would change their preferred temperature by as much as 3°F, which makes this range unrealistic.
- Stakeholders also expressed that they believe that the 10th percentile of indoor temperature history is an accurate representation of preferred comfort temperature.

Guidehouse

Different Percentiles for Preferred Comfort Temperature

- Per stakeholder request, Guidehouse also tested using the 15th and 20th percentiles, instead of the 10th percentile for selecting the preferred comfort temperature.
- Using an assumption of the 20th percentile of indoor temperature history instead of the 10th percentile led to:
  – An average increase in preferred comfort temperature of 0.5°F (HER) and 0.6°F (Non-HER).
  – A decrease in runtime savings of ~3 percentage points.





ENERGY STAR Analysis Results: Setback Behavior

Guidehouse

Setback Behavior

Parameters Before Installation

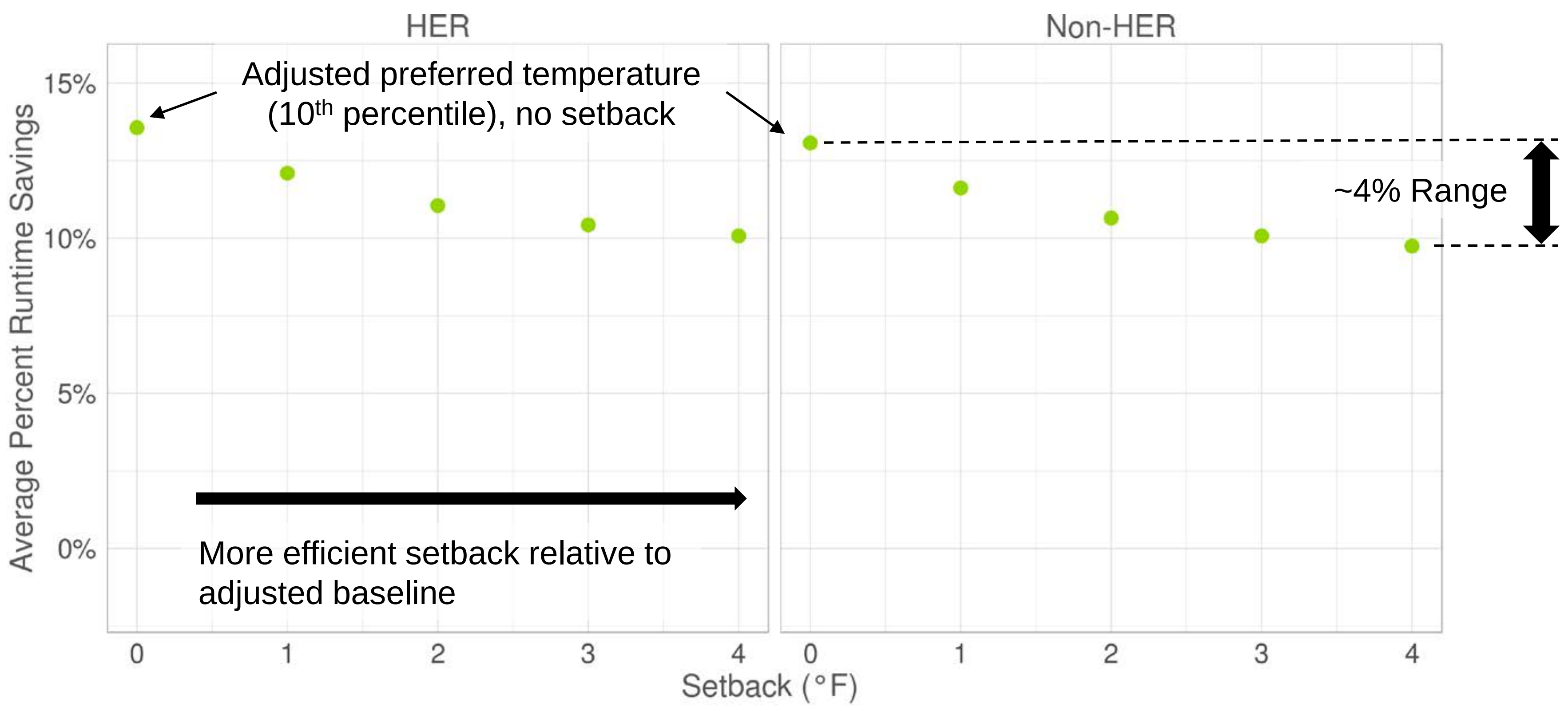
Guidehouse explored the sensitivity of savings estimates to an assumed setback behavior before installation, ***relative to the adjusted baseline***.

- **Setback behavior** – Estimated a range of runtime savings from the adjusted ENERGY STAR algorithm (and compared with standard ENERGY STAR rating) with the following parameters:
  - A range of baseline setpoint changes from ***0 to +4°F*** for the period during the day when no one is home, ***8 AM to 5 PM***
    - Note that 0°F means no setback and 4°F is the most aggressive setback tested
  - ***Do not apply a setback for other times of the day*** (i.e., during the evening when people are home and overnight)
  - Daytime setback is applied for ***weekdays only***
  - The evaluators explored available data to estimate ***what percentage of homes may use a setback***

Setback Behavior

Savings Estimates

- Varying the daytime setback from 0 to 4°F between 8 AM to 5 PM on weekdays results in estimated savings with a range of approximately 4%.
  - For a preferred comfort temperature of the 10th percentile, the savings range from 10-14%. For other comfort temperatures, this range may differ.



Setback Behavior

ComEd Participant Survey

The ComEd participant survey provides some indication of how many customers are home or away on summer weekdays.

- The 65% of respondents to the ComEd participant survey who reported that someone was home during the day on summer weekdays are least likely to use a setback.
- The 15% of respondents who reported no one was at home during the day on summer weekdays are the most likely to utilize a setback.
- The survey provides a qualitative understanding of how many customers might use a setback, but is insufficient to determine exact behavior.

Is someone in your household typically home during the day on summer weekdays?
(n=1,220)

Response	Frequency	Percentage of Responses
Yes	791	65%
No	188	15%
Sometimes	241	20%

* ComEd Advanced Thermostats Research 2018 Participant Survey Results, p. 21. https://ilsag.s3.amazonaws.com/ComEd-Tstat-Participant-Survey-Results-Final-2020-01-21.pdf

ENERGY STAR Analysis Results: Additional Considerations

Guidehouse

Additional Considerations
Not Currently Addressed

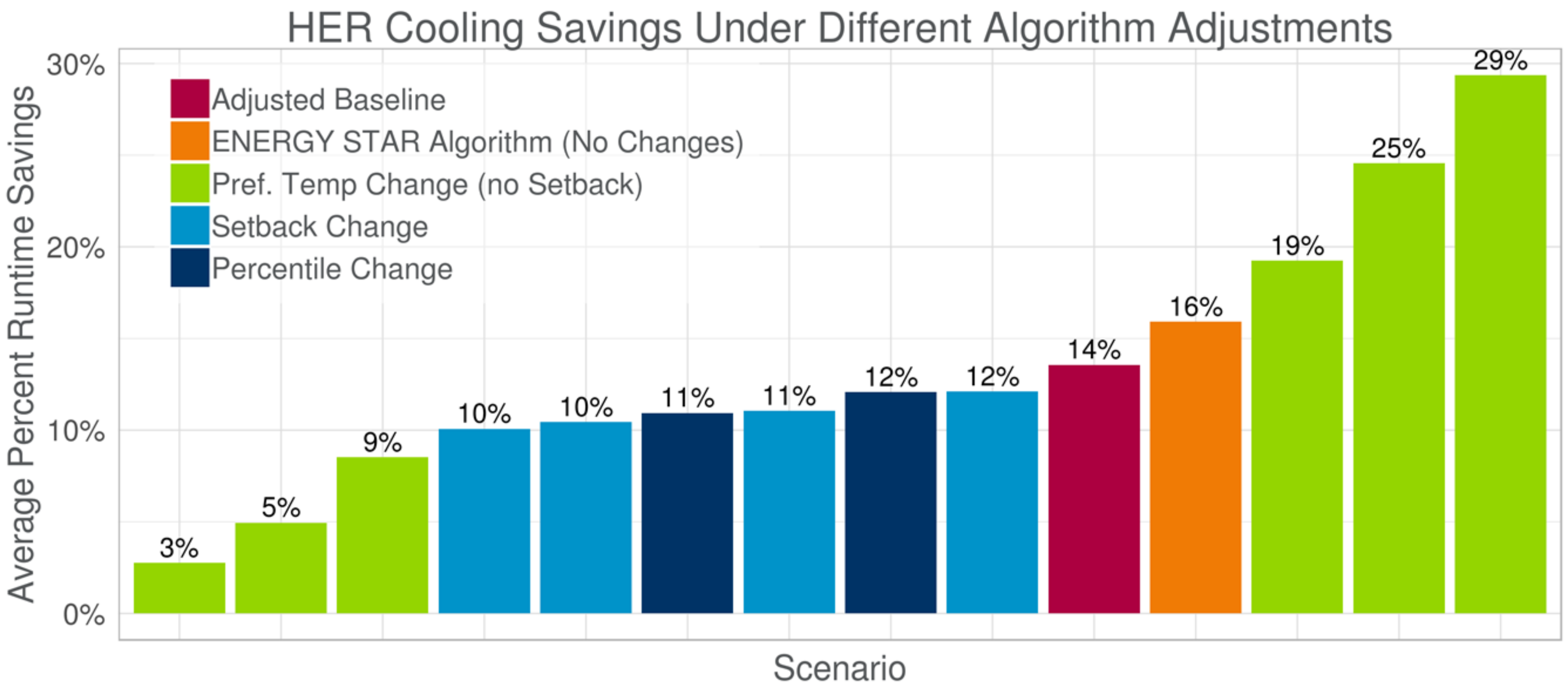
Additional considerations may lead to an increase or decrease in estimated savings, not captured by the ENERGY STAR method :

Potential Increases	Potential Decreases
• Some customers may increase fan consumption by implementing fan cycling during times when HVAC was off, when they did not have or use that capability before • Some customers have a second source of cooling or heating that may pick up more of the load if setback is only implemented on one (e.g., large homes with 2 furnace/AC combinations)	• The installation of an advanced thermostat may lead to more energy efficient behavior and increase savings, such as: – Nudges towards more energy efficient behavior or setpoints – Better use of multi-stage HVAC units or better control of back up resistant heat – Other spillover effects

- An adjustment factor for these effects would be necessary; however, we do not have sufficient data for exploring or deriving such an adjustment directly
- The ENERGY STAR algorithm produces an estimate of percent runtime savings, which will depend on when and under what operating conditions runtime savings occur. In absence of additional data, percent runtime and energy savings could be assumed to be equivalent; further research would be required to quantify any differences
- Evaluators may not be able to verify manufacturer-reported ENERGY STAR ratings for the IL TRM without access to underlying telemetry data.

ENERGY STAR Analysis

Range of Savings (HER)



Adjusted Baseline, Preferred temperature +1 to +3°F

Adjusted Baseline, Setback 0 to 4°F
Adjusted Baseline, 15th and 20th Percentile

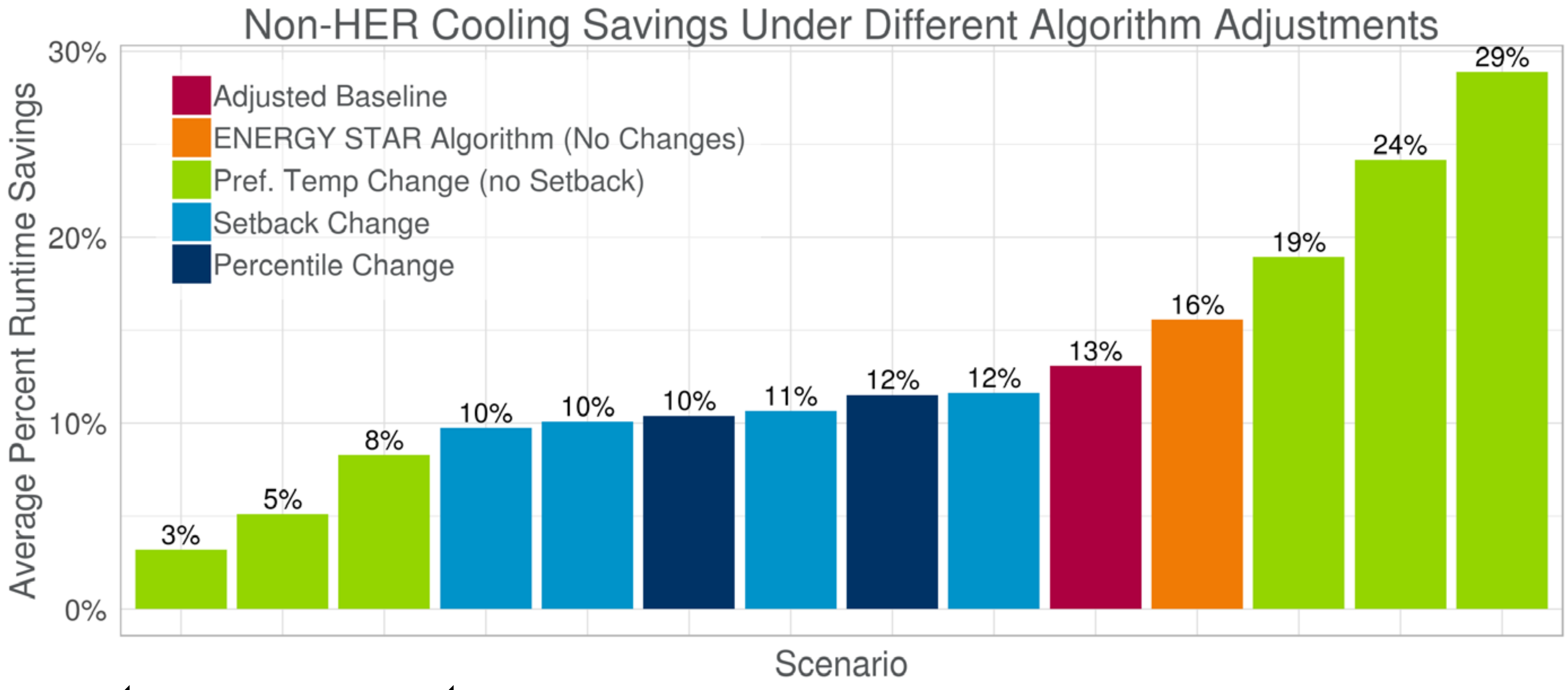
Adjusted Baseline, Preferred Temperature -1 to -3°F

- Estimated savings vary based on assumptions made regarding how customers used their thermostat.
- Savings estimates for analyzed scenarios range from 3% to 29% of cooling runtime.
- Guidehouse acknowledges that some stakeholders assert a range of parameters that they consider to be a reasonable range of expected behavior, which results in savings estimates between 10% and 14% of cooling runtime.
- Guidehouse found similar savings estimates for non-HER customers (see next slide).
- Guidehouse did not estimate coincident peak demand savings using the ENERGY STAR method.

Guidehouse

ENERGY STAR Analysis

Range of Savings (Non-HER)



Adjusted Baseline, Preferred temperature +1 to +3°F

Adjusted Baseline, Setback 0 to 4°F
Adjusted Baseline, 15^{th} and 20^{th} Percentile

Adjusted Baseline, Preferred Temperature -1 to -3°F

- Estimated savings vary based on assumptions made regarding how customers used their thermostat.
- Savings estimates for analyzed scenarios range from 3% to 29% of cooling runtime.
- Guidehouse acknowledges that some stakeholders assert a range of parameters that they consider to be a reasonable range of expected behavior, which results in savings estimates between 10% and 14% of cooling runtime.
- Guidehouse found similar savings estimates for HER customers (see previous slide).
- Guidehouse did not estimate coincident peak demand savings using the ENERGY STAR method.

Guidehouse

Conclusion

Guidehouse

Conclusion

- Guidehouse compared the results of the econometric and ENERGY STAR analyses and found that the results yielded materially different estimates of savings.
  - The econometric analysis estimated between 6.4% – 7.8% cooling energy savings
  - The ENERGY STAR analysis estimated between 10% – 14% cooling runtime savings (stakeholder estimated range)
- These differences may be different due to:
  - Different adjustments made to each analysis (e.g. for future TO savings),
  - Pre-installation behavior that was not able to be incorporated into the ENERGY STAR analysis, and/or
  - Uncertainty with respect to the comparison group used for the econometric analysis, related to potential time-based selection bias or other pre-existing differences
- Guidehouse made recommendations regarding updates to the IL TRM, including parameters related to cooling reduction factor, ISR, and coincident peak demand savings; however, updates to IL TRM v9 were determined through discussions among the TAC and the Stipulating Parties.
  - Specifically, the Advanced Thermostats Agreement for IL TRM v9 describes the agreement reached regarding the cooling reduction factor.
- Additional details on the analysis can be found in the Appendices that follow in this report.

Appendix: Econometric Analysis Methodology

Guidehouse

Appendix: Econometric Analysis – Available Data

Guidehouse

Data Sources

Data	Description

AMI Consumption Interval Data	• Consumption (30-minute interval) for March – October from 2017 and 2018
	• 104,827 participants, who received a rebate for a smart thermostat in between October 2017 and July 2019
	  • 38,224 of these had thermostats rebated between October 2017 and April 2018 and are participants in this study
	  • 66,603 of these had thermostats rebated between October 2018 and July 2019 and are "future" participants in this study and make up the potential comparison group

Participation Tracking Data	• ComEd programs including Advanced Thermostats as a measure for PY9, CY2018, and CY2019
PRIZM Data	• Codes that indicate demographic segmentation as determined by Claritas, e.g. by wealth, life stage, household composition, and social group
Weather Data	• National Oceanic and Atmospheric Association (NOAA) hourly historical temperatures • March – October for 2017 and 2018 for relevant ZIP codes

Weather data available at: https://www.ncdc.noaa.gov/cdo-web/search
PRIZM code descriptions available at: https://claritas360.claritas.com/mybestsegments/#segDetails

Participation Channels

- Participants are customers who received a rebate for an advanced thermostat through a number of ComEd programs, as shown in the adjacent table.
  - The majority of participants received a rebate through the Appliance Rebates program.
- We assume that the rebate application date coincides with thermostat installation, although there may be a time difference (e.g. a person may install their thermostat before / after applying for their rebate)
- For this study, we defined the following:
  - **Study Participants**: These are treatment customers, who received a rebate after Summer 2017 and before Summer 2018.
  - **Future Participants**: These are comparison customers, who received a rebate between October 2018 and July 2019, **who did not have an advanced thermostat rebated in the study period.**

Program	Percent of Study Participants	Percent of Future Participants
Appliance Rebates	92.7%	93.2%
Residential HVAC	5.4%	4.3%
Home Energy Assessment	1.9%	2.4%
Single-Family Illinois Home Weather Assistance	<0.1%	0.1%
Multifamily	-	<0.1%

Customer Attrition

- Guidehouse received AMI data for 104,827 customers who had data for summer 2017 and/or summer 2018.
  – Of those, 87,589 customers had at least some data for both pre- and post-rebate periods.
  – After cleaning the data, 66,054 customers had sufficient data for inclusion in the analysis.
- Data cleaning includes the following steps:
  – Remove erroneous data (including duplicates, negative reads, and frequent instances of zero usage)
  – Remove outlier observations*
  – Remove customers with insufficient data in the pre- and/or post-rebate periods**
  – Remove customers who received a rebate for other measures in PY9, CY2018, and/or CY2019
- Most accounts were dropped due to insufficient data (15.9% of 104,827 dropped) or installation of other measures (11.5% of 104,827 dropped)

Data Set	Study Participants	Future Participants
Raw Data	38,224	66,603
Has some data in both pre/post (may be incomplete)	32,151	55,438
Study Data	23,515	42,539

* > 200 kWh in a single 30-minute interval
** < 135 out of 153 days of data in either pre- and post-periods

Appendix: Econometric Analysis: Comparison of Current and Future Installers

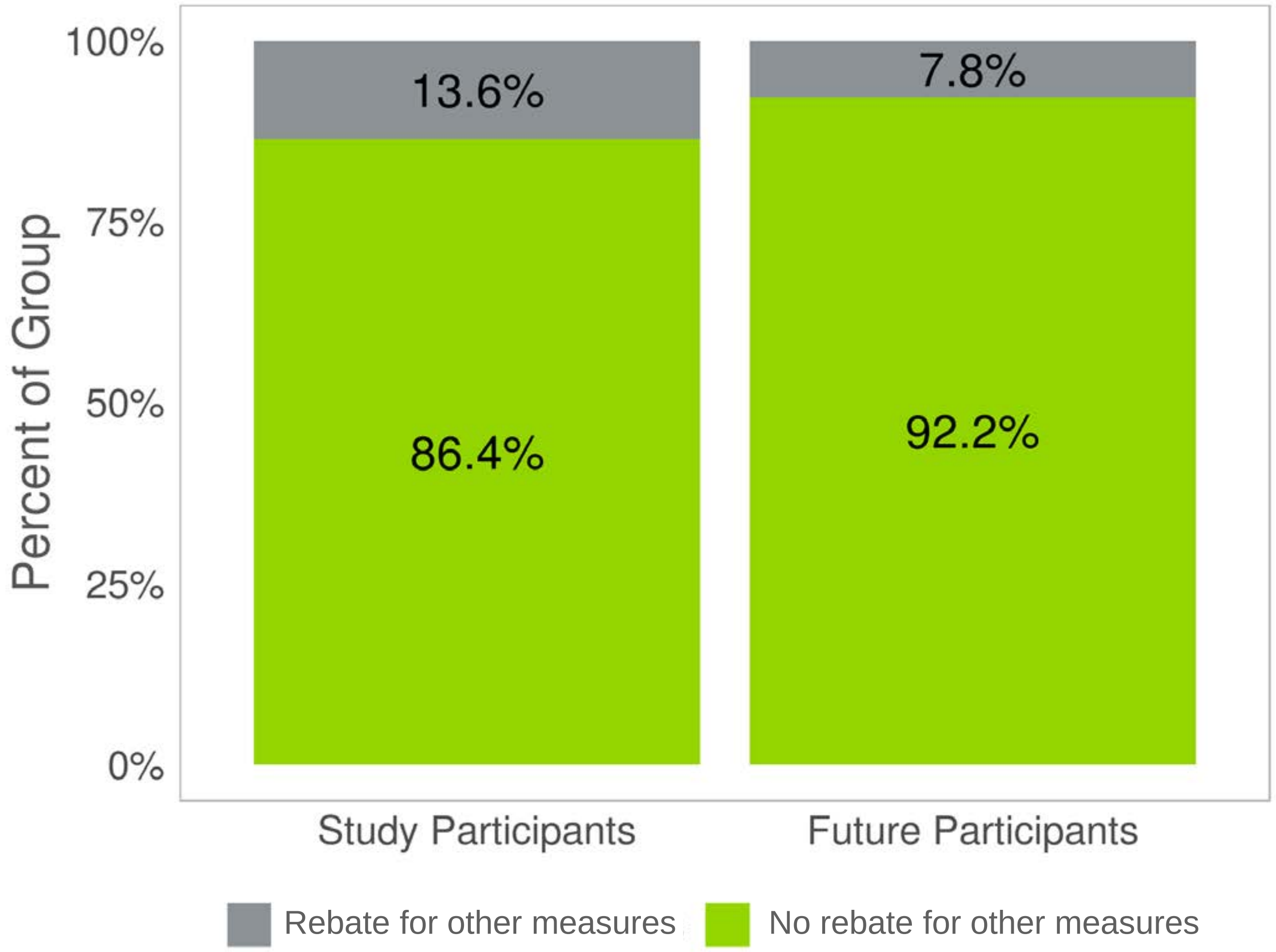
Guidehouse

Overview

- ***Before matching,*** we compared study participants and future participants to assess similarity on several characteristics, including:
  - Timing (i.e., month of year) of smart thermostat rebate
  - Participation in other EE programs, including the HER program
  - Geographic location
  - Demographic characteristics
  - Energy use in summer prior to installation
- The comparison of study and future participants may reveal differences that inform the selection of matching variables.
- The ideal comparison group will have similar distributions of observable variables that may influence energy use and savings.
- Selection of a comparison group is a pre-processing step for the regression analysis, which will control for remaining differences as best as possible.
- The following balance checks include all participants (HER and non-HER).
  - The final analysis analyzed HER participants separately from HER non-participants, as discussed later in this section.

Participation in Other Programs

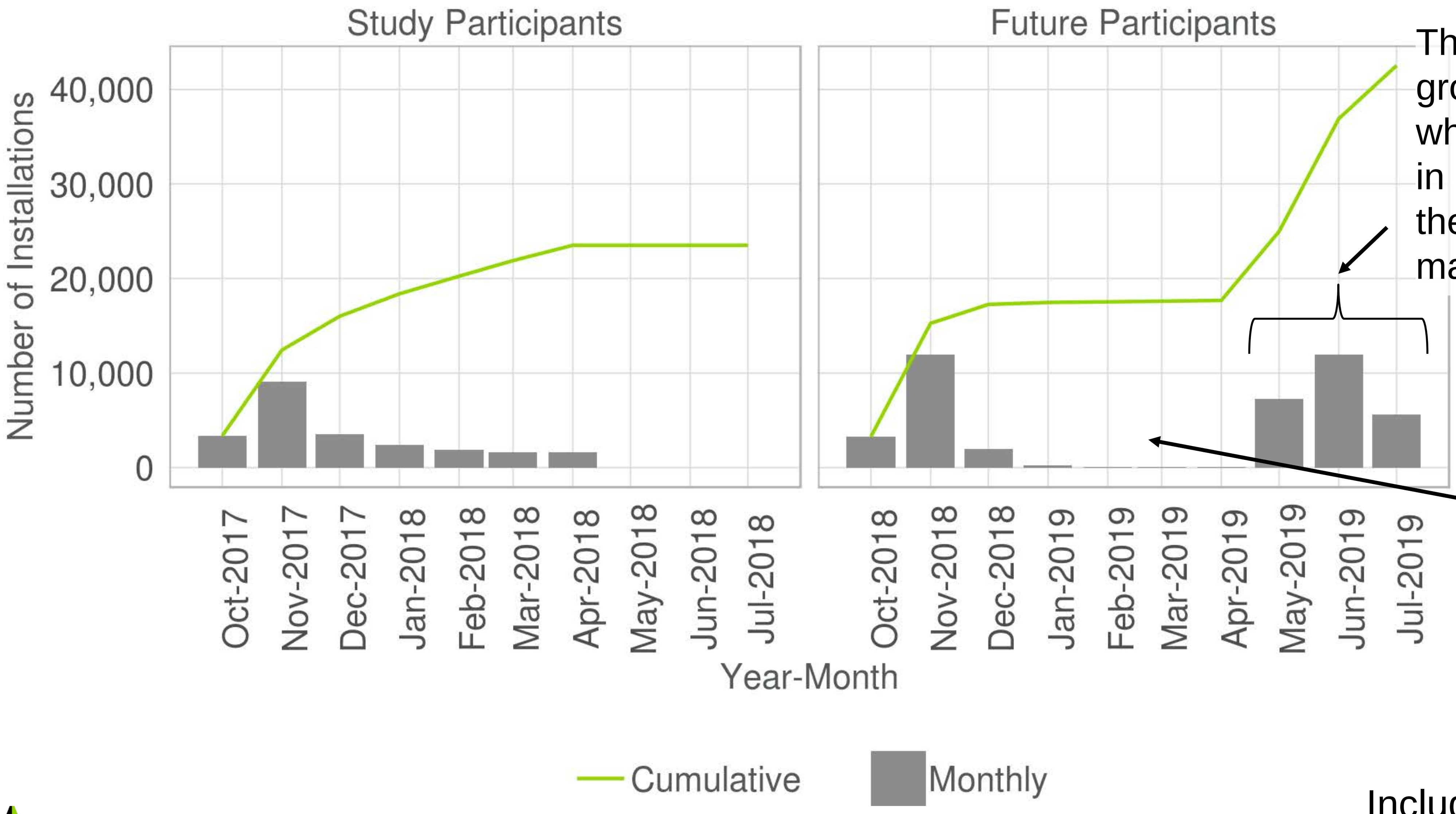
- Rebates for other measures reflect program tracking data from PY9 through early CY2019.
- Study participants were more likely than future participants to have received a rebate for additional measures.
  - Future participants had less time to install other measures, through early CY2019 (the latest tracking data available when this research was undertaken)
- Customers who installed other measures were excluded from this study, to mitigate the effect of installing other measures.
  - All comparisons in the rest of this report exclude such customers



Includes HER & Non-HER

Rebate Dates

November includes many rebates for both study and future participants.



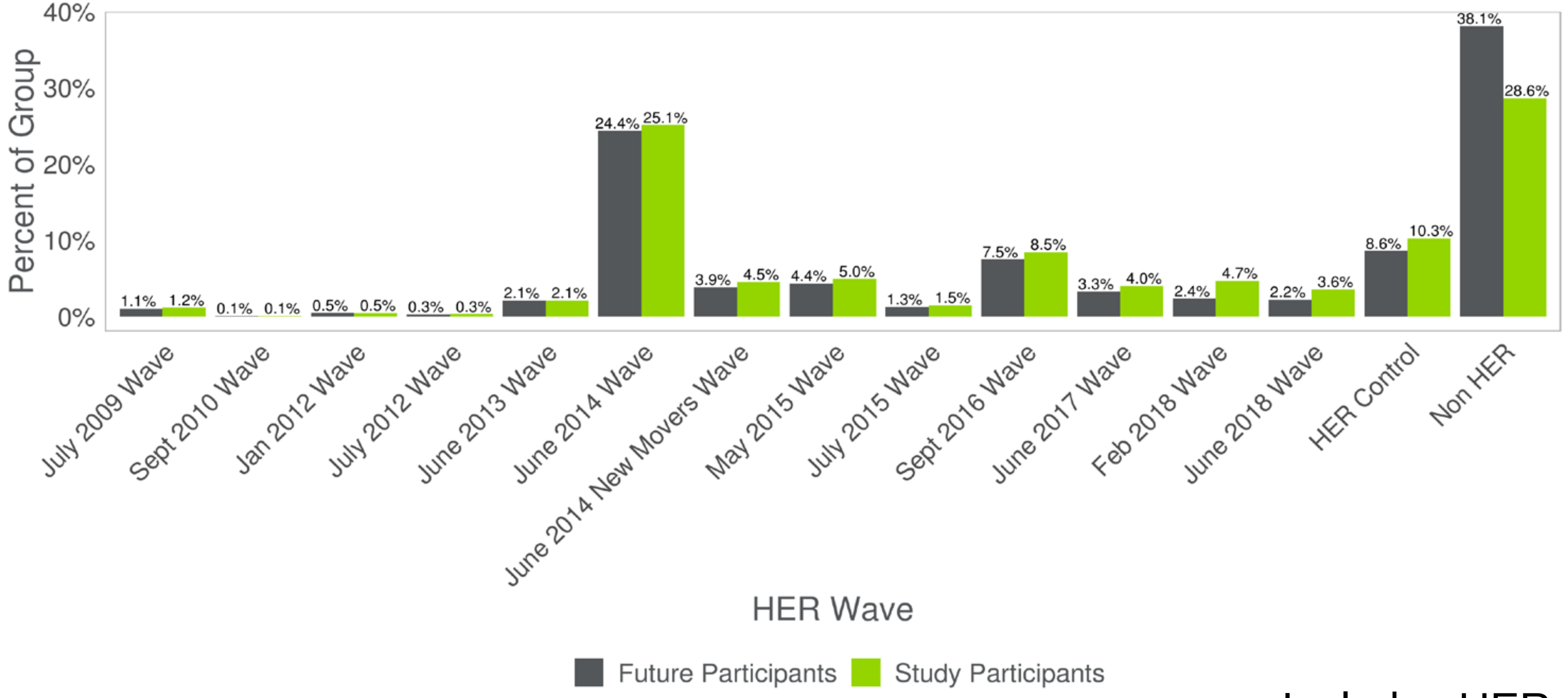
The future participants group includes customers who received a rebate in summer 2019, to increase the pool of potential matches.

Few rebates occurred in January to April 2019.

Includes HER & Non-HER

Home Energy Report Overlap

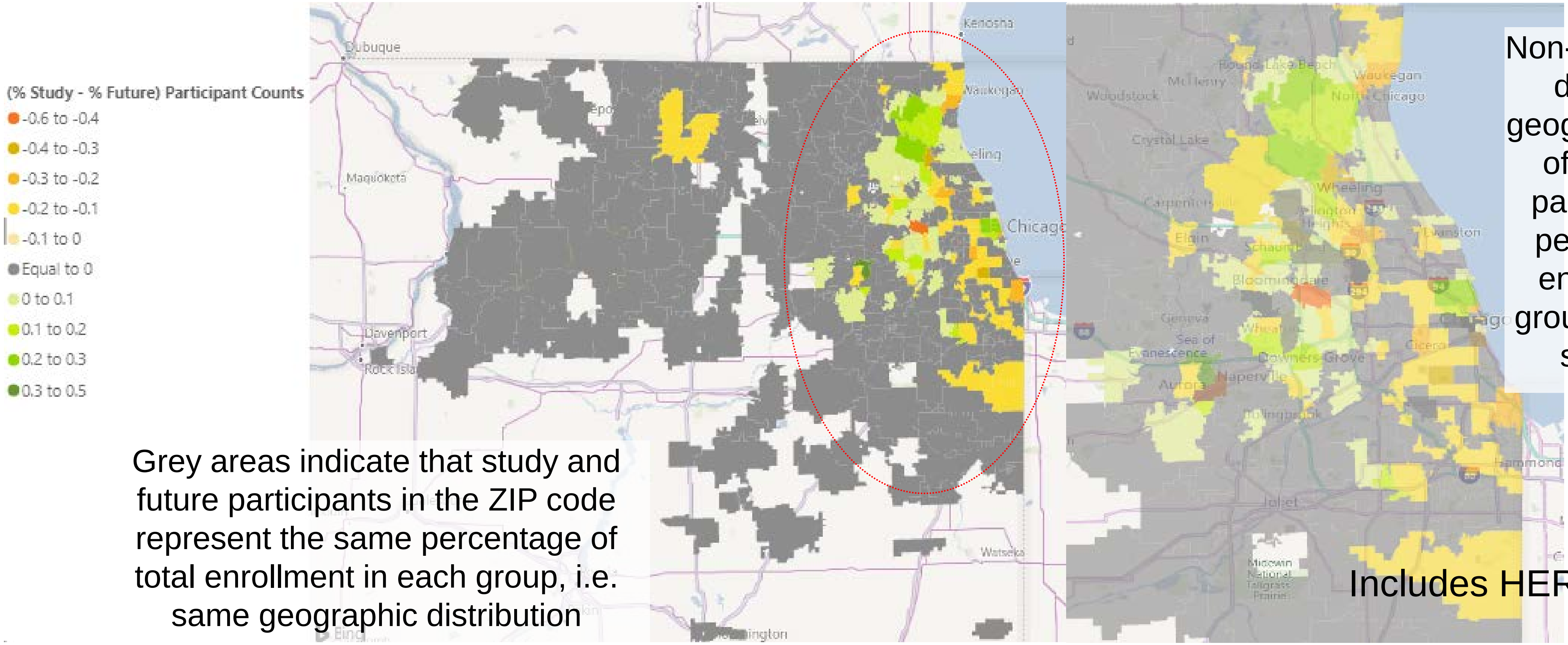
- Study participants are more likely than future participants to be assigned to an HER wave.
- Participants in both groups who are assigned to an HER wave are distributed across HER waves at similar rates.
- Differences in distribution between study and future participants (e.g., for Non-HER) will be accounted for, e.g. through matching and/or by including variables in the regression model. Guidehouse ultimately analyzed HER and non-HER customers separately.



Includes HER & Non-HER

Location

- In general, study and future participants are similarly distributed across ComEd's service territory. Differences in the population distribution are less than 0.6% across all ZIP codes.
  - A 0.6% percentage point difference means that study participants in a particular ZIP code represent 0.6% more of all study participants, compared with the analogous percentage for future participants.
  - 46 ZIP codes contain study participants and no future participants and 50 ZIP codes contain future participants and no study participants. This accounts for 0.5% of the analysis population.
- ZIP codes near Aurora and Addison had the largest discrepancies.



Grey areas indicate that study and future participants in the ZIP code represent the same percentage of total enrollment in each group, i.e. same geographic distribution

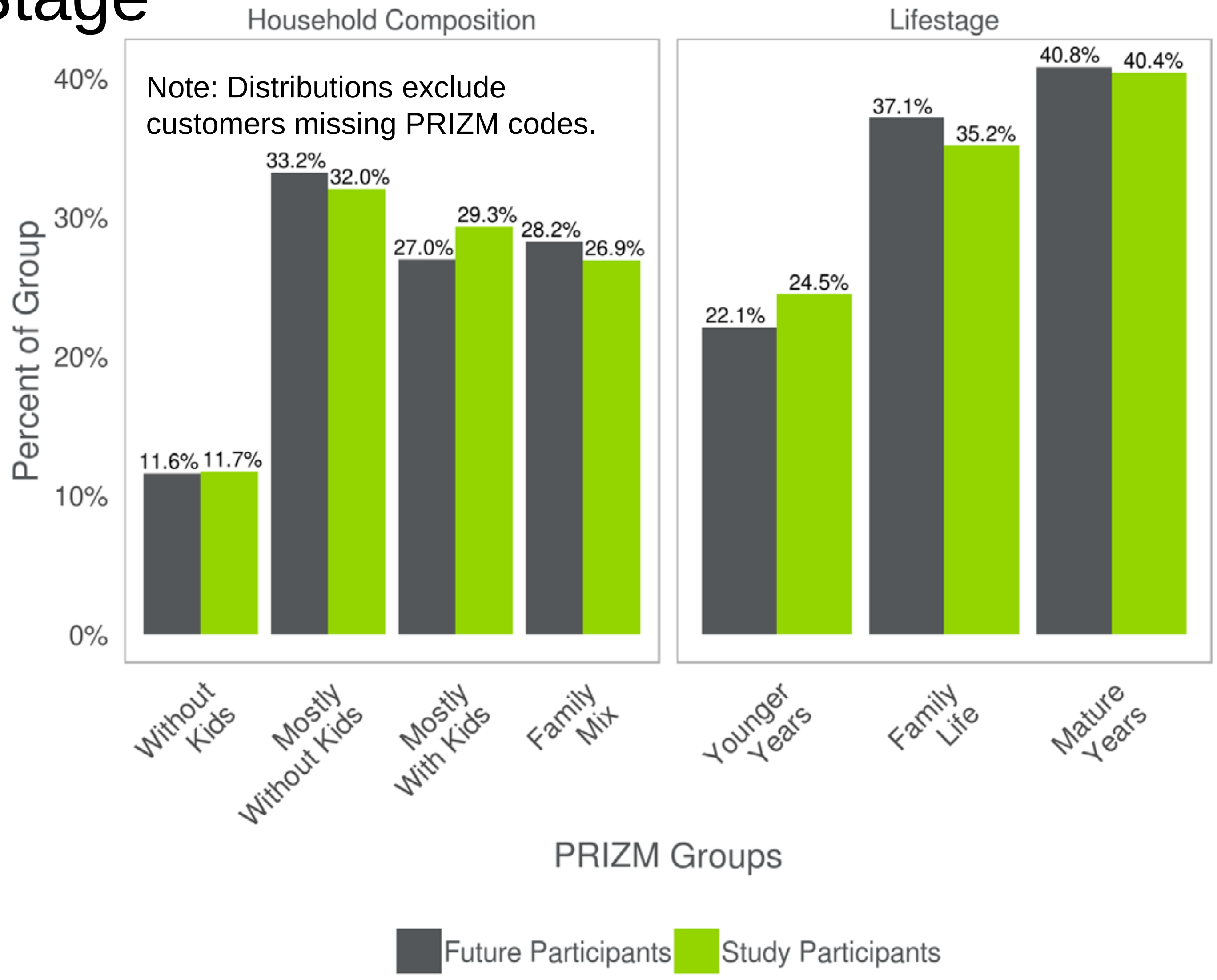
Non-grey areas indicate differences in the geographic distributions of study and future participants, e.g. the percentages of total enrollment for each group of participants is slightly different.

Includes HER & Non-HER

Demographic Characteristics

Household Composition & Life Stage

- Only 3% of study participants were missing a PRIZM code, compared to 12% of future participants. This may be due to the fact that future participants may be newer customers that haven't been assigned a PRIZM code yet. ComEd periodically refreshes PRIZM data for its customers.
- Some differences exist:
  - Study participants are more likely than future participants to be categorized as "Mostly With Kids", and less likely to be categorized as "Mostly Without Kids" or "Family Mix."
  - Study participants are more likely to be categorized as "Younger Years" than future participants, and less likely to be categorized as "Family Life.“
- Differences in distribution between study and future participants need to be accounted for, e.g. through matching and/or by including variables in the regression model (discussed later).

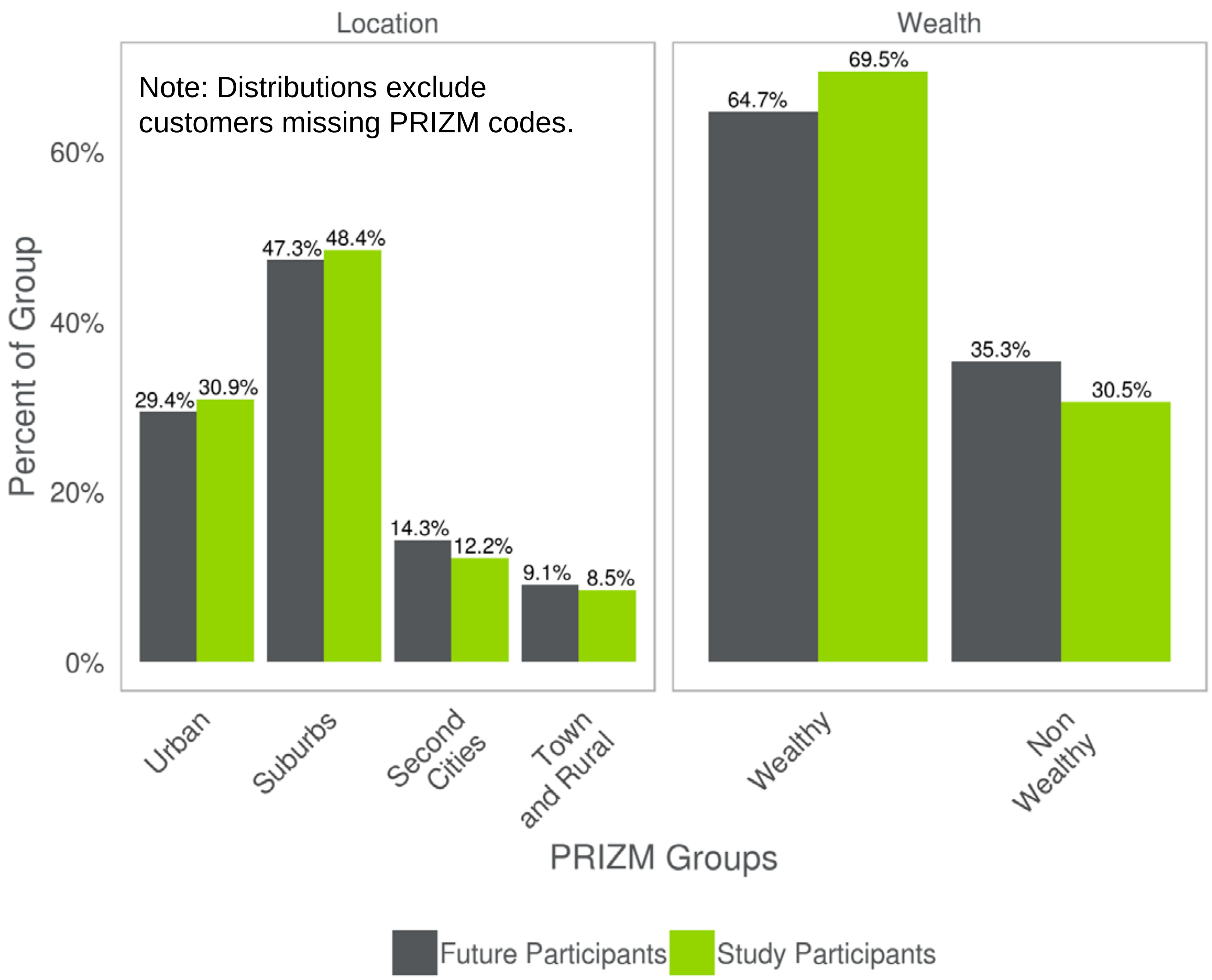


Includes HER & Non-HER

Demographic Characteristics

Location & Wealth

- Only 3% of study participants were missing a PRIZM code, compared to 12% of future participants.
- Some differences exist:
  - Study participants are more likely than future participants to live in urban and suburban areas, and less likely to live in "second cities" or rural areas.
  - Study participants are more likely to be categorized as wealthy than future participants.
    - Wealthy segments have median household incomes greater than $80,000 (in 2017, in 2017 dollars)
- Differences in distribution between study and future participants need to be accounted for, e.g. through matching and/or by including variables in the regression model (discussed later).

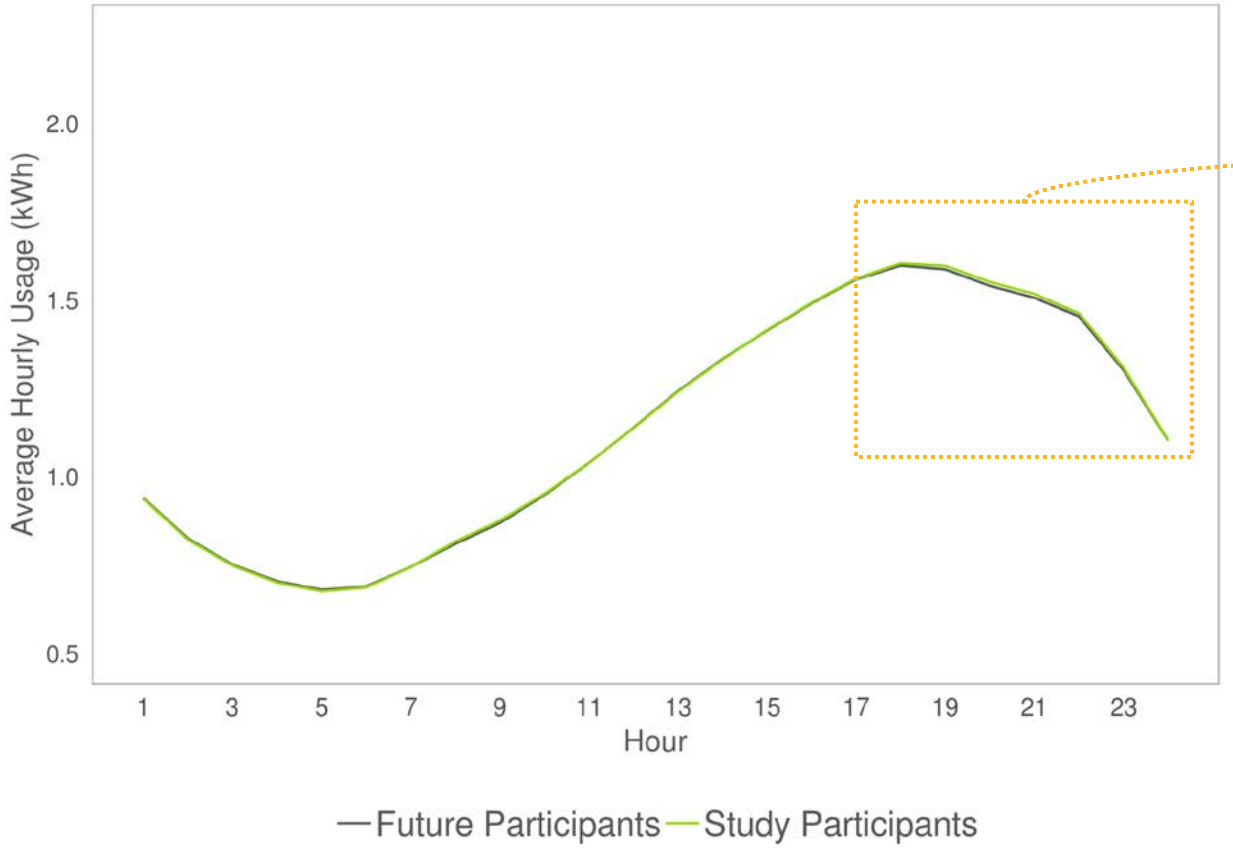


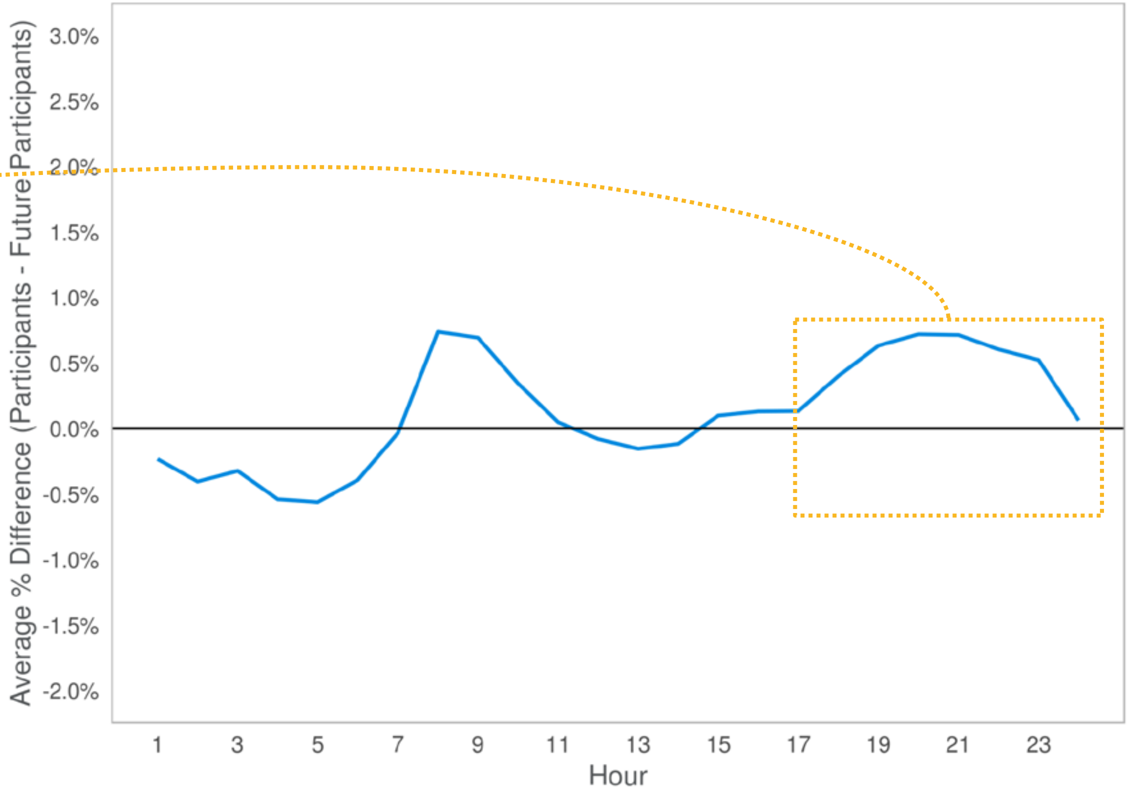
Includes HER & Non-HER

Guidehouse

Hourly Load Shapes in Pre-Installation Summer

- In general, study and future participants have similar average load shapes during the pre-installation summer, with absolute differences less than 1% in all hours.
- Compared to future participants, study participants have slightly higher usage in the morning and evening hours (7-9 AM, 6-11 PM).

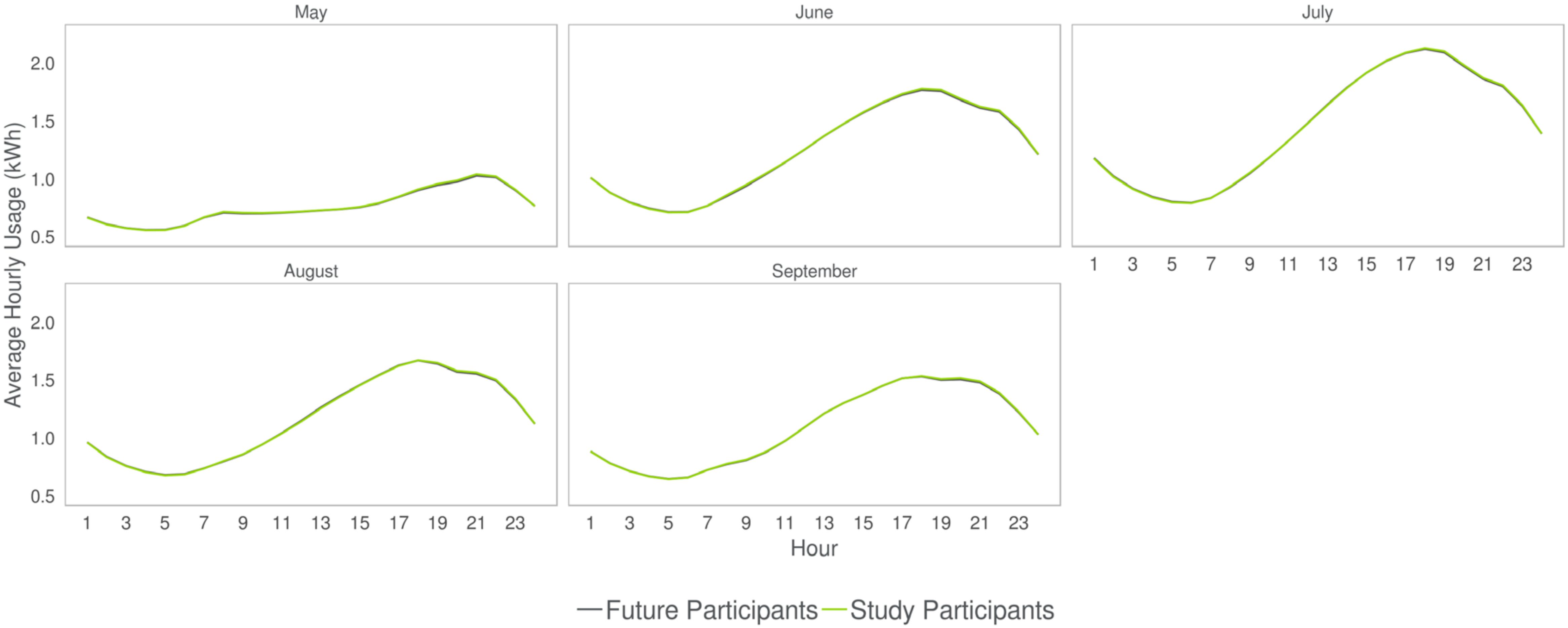




Includes HER & Non-HER

Hourly Load Shapes in Pre-Installation Period

- In general, study and future participants have similar average load shapes in each month of the pre-installation summer, with absolute differences less than 1.3% in all hours.*

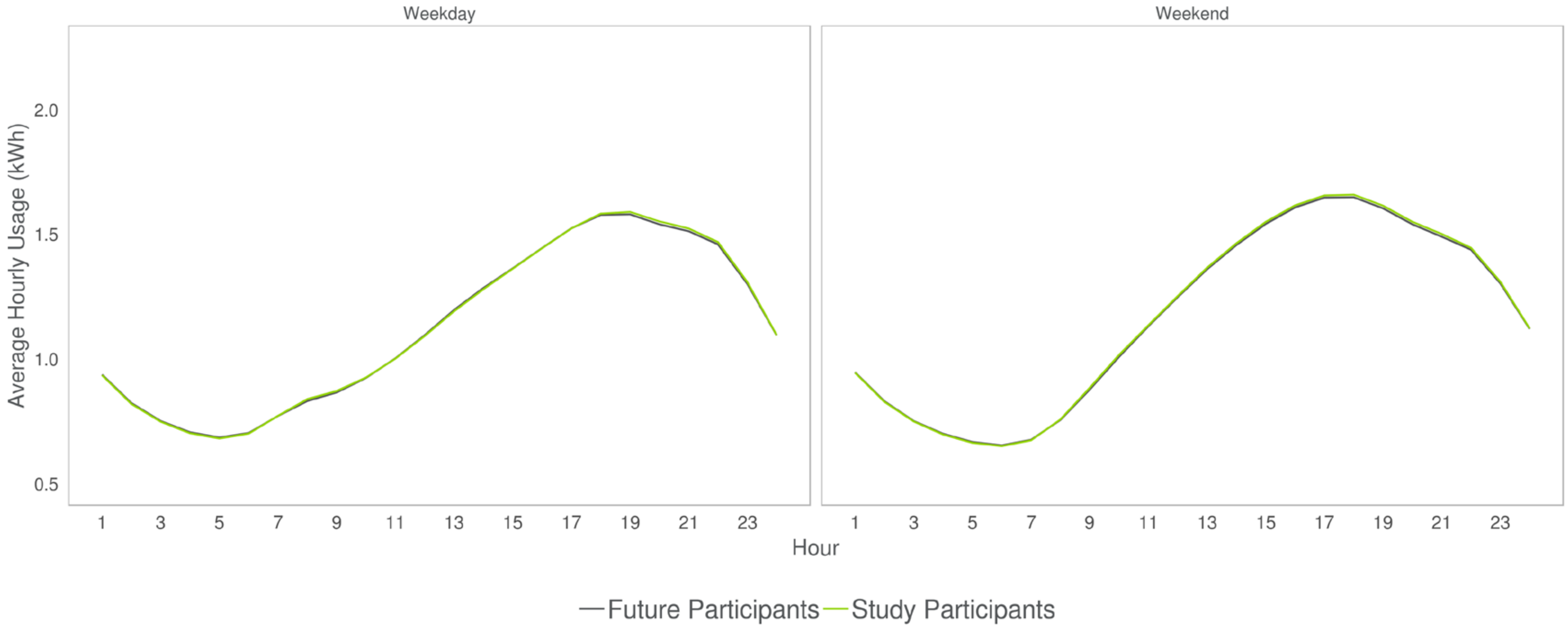


* Since some months exhibited smaller differences than others, the highest average absolute difference is higher in any given month (1.3%) than when averaging over all months (1%).

Includes HER & Non-HER

Hourly Load Shapes in Pre-Installation Period

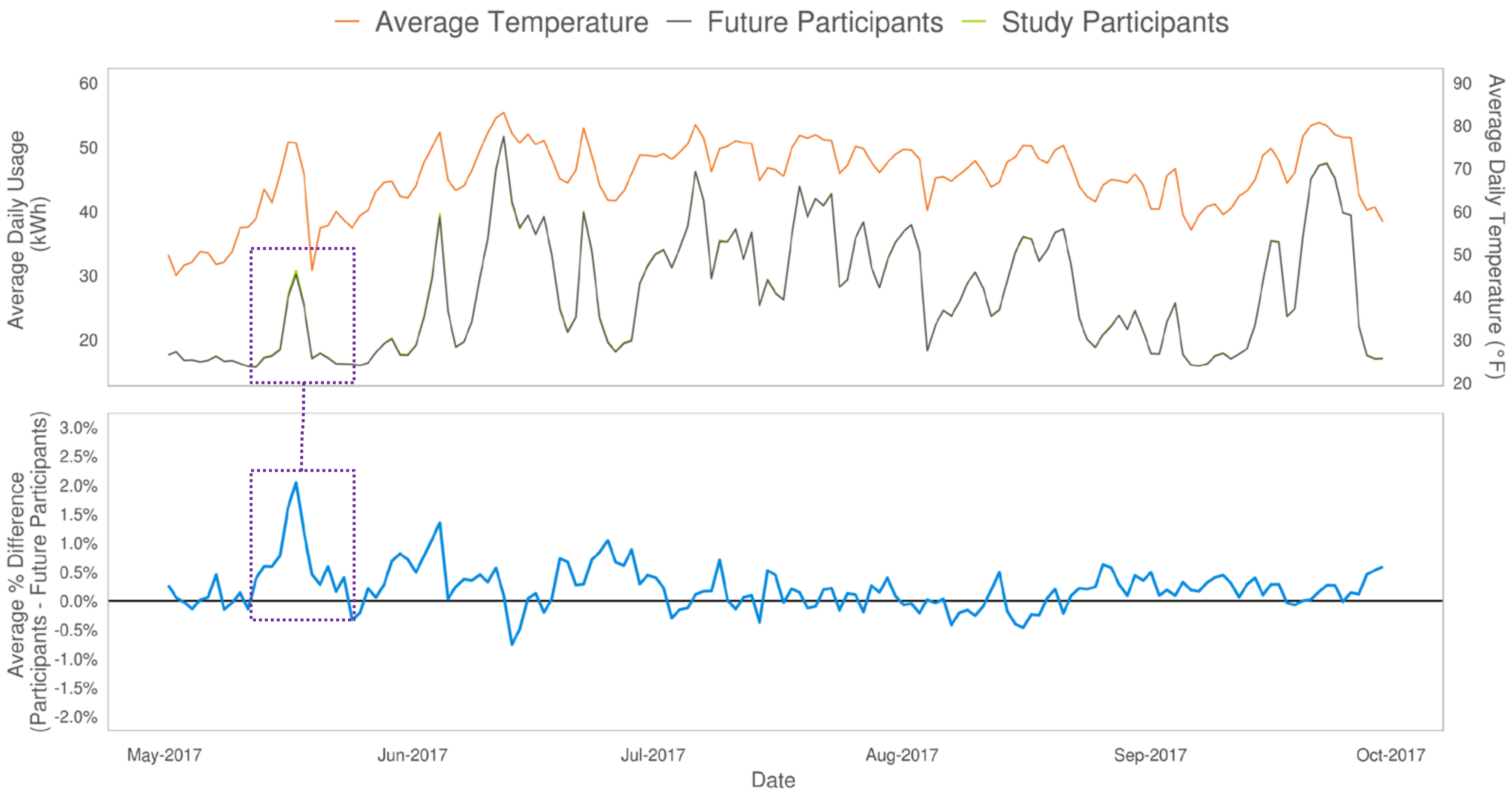
- In general, study and future participants have similar average load shapes on weekdays and weekends during the pre-installation summer, with absolute differences less than 1% in all hours.



Includes HER & Non-HER

Daily Usage in Pre-Installation Period

- In general, study and future participants have similar average daily usage patterns during the pre-installation summer, with absolute differences less than 1% on nearly all days.
- The largest discrepancy occurs on an unseasonably hot day in late May.
- Differences oscillate between positive and negative throughout the summer, with an average of +0.23%.



Includes HER & Non-HER

Guidehouse

Summary

- Guidehouse concluded that future participants serve as a high-quality comparison group, and further refinements via matching are not required:
  - Study and future participants have generally similar distributions of key demographic variables, as well as usage patterns in the pre-installation summer. The evaluators note that a comparison group ***does not need to provide perfect alignment across all variables to be considered high-quality.***
  - ***To account for remaining discrepancies between study and future participants as best as possible,*** usage during the pre-installation summer and demographic characteristics are included in the regression model.
- As a robustness check and to provide stakeholders additional context, Guidehouse explored potential matched comparison groups to see if alignment between study and future participants could be improved further.
  - Discussed in the next section, Guidehouse concluded that matching did not improve the overall quality of the comparison group as usage differences were exacerbated by exact matching on other variables.
- While assessing sensitivity of model results to various analysis decisions (including the customer set, model specification, and time of day), Guidehouse discovered that the results varied substantially for HER participants and HER non-participants. As a result, Guidehouse re-examined the comparison group quality for each of these subgroups (HER participants and HER non-participants) and discovered that usage for HER participants was balanced across study and future participants, while usage for HER non-participants was not well-balanced. This discovery informed the decision to analyze each group separately.
  - Balance checks for HER participants are shown on the next slides.
  - Guidehouse investigated non-HER participants separately, but ultimately concluded that a comparison group of sufficient quality could not be found with the available data to recommend using for estimating savings, described in the next section.

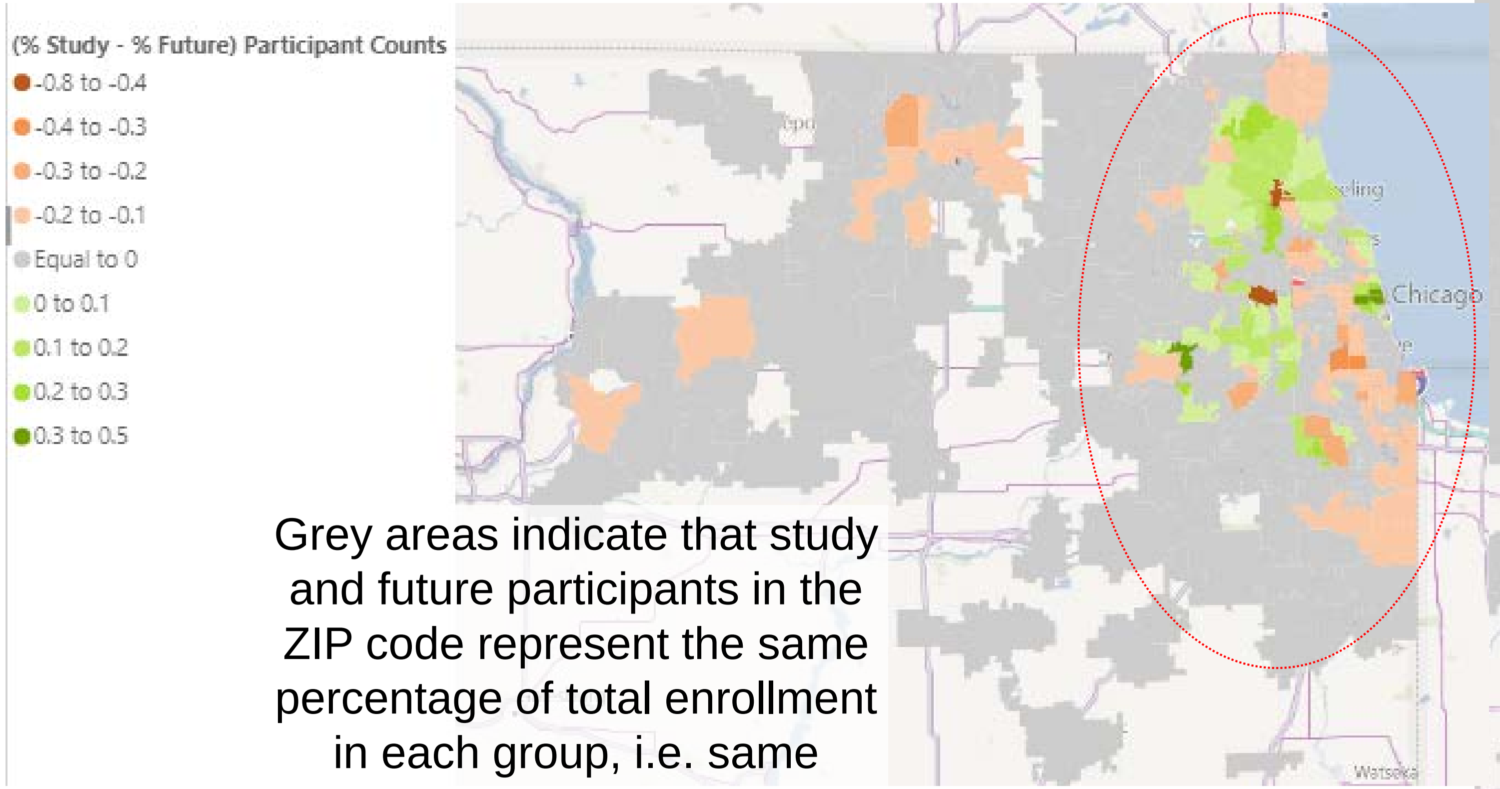
HER: Comparison of study & future participants

Demographics

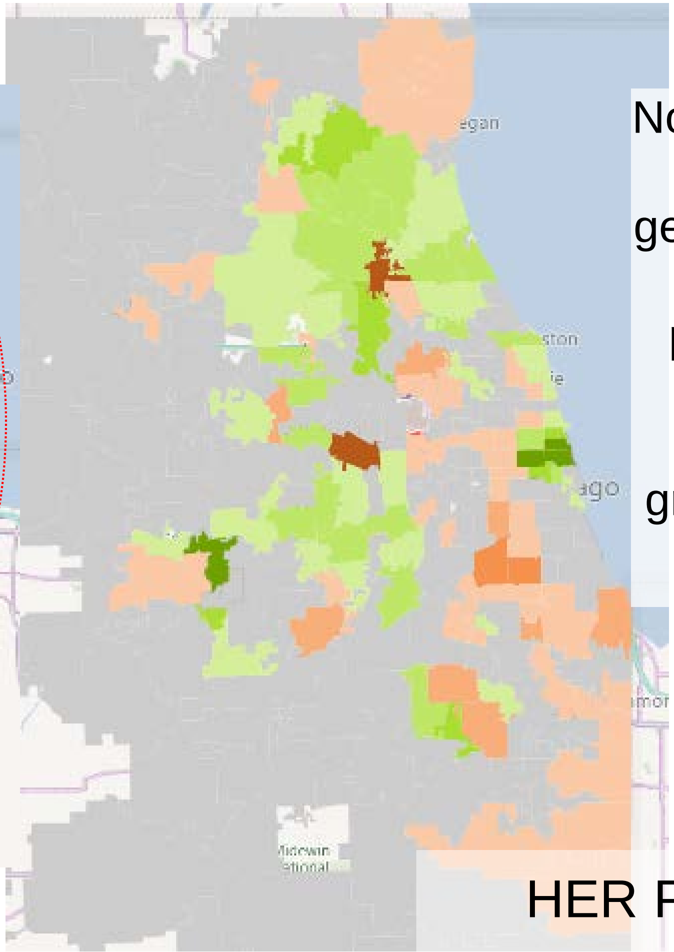
- 2% of HER study participants were missing a PRIZM code, compared to 1% of HER future participants.
- Similar to the distributions comparing all study and future participants, the demographic distributions for HER participants exhibit some differences, as shown on the next slides.
- Differences are generally smaller in magnitude for HER participants than for all study and future participants.
- Differences in distributions between study and future participants are mitigated by the inclusion of PRIZM group variables in the regression model.

HER: Location

- In general, study and future participants are similarly distributed across ComEd's service territory. All but one of the 393 ZIP codes represented in the study differ by less than 0.5%. The remaining ZIP code had a discrepancy of 0.86%.
  - A 0.5% percentage point difference means that study participants in a particular ZIP code represent 0.5% more of all study participants, compared with the analogous percentage for future participants.
  - 30 ZIP codes contain study participants and no future participants and 45 ZIP codes contain future participants and no study participants. This accounts for 0.7% of the analysis population.
- ZIP codes near Aurora and Addison had the largest discrepancies.



Grey areas indicate that study and future participants in the ZIP code represent the same percentage of total enrollment in each group, i.e. same geographic distribution



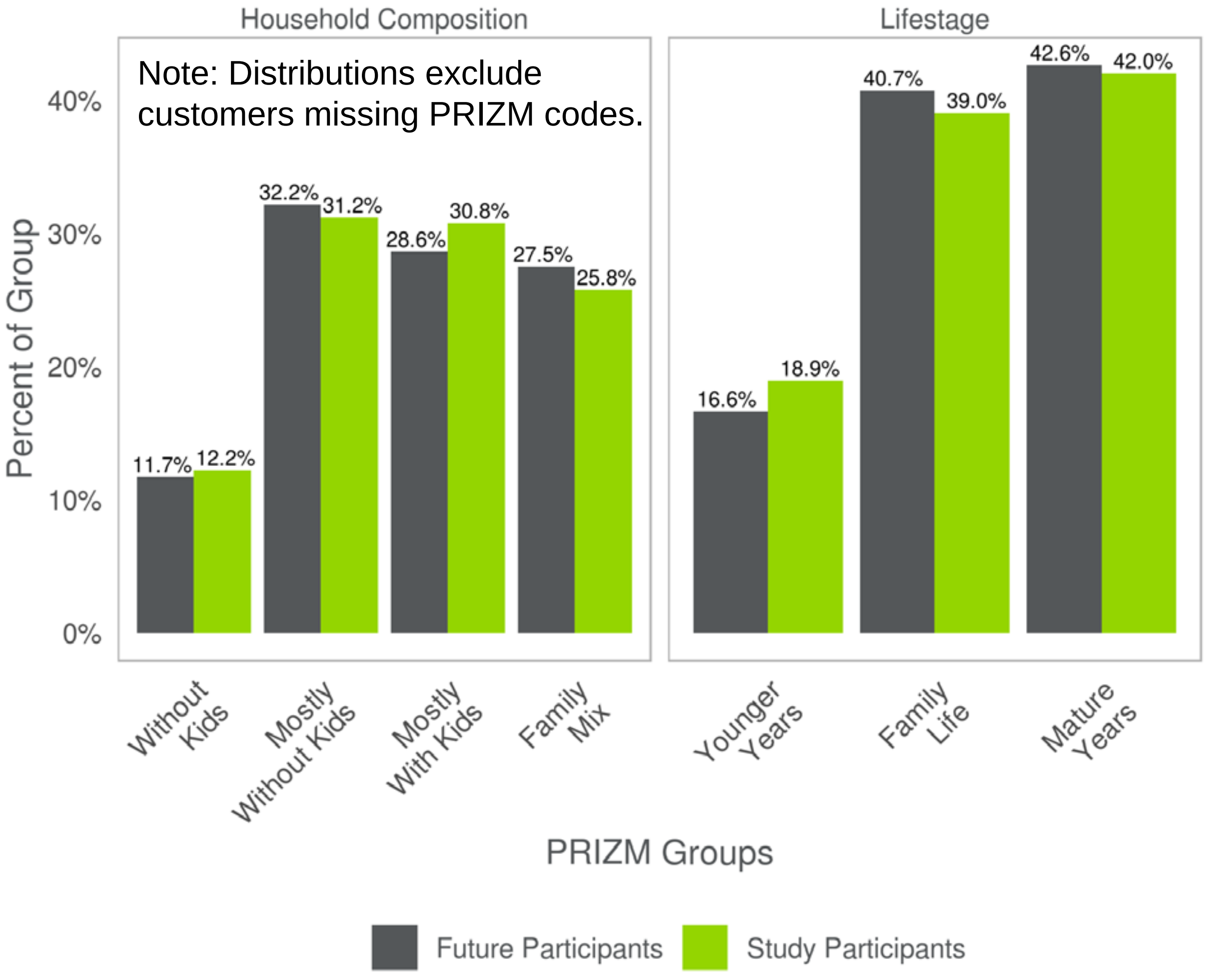
Non-grey areas indicate differences in the geographic distributions of study and future participants, e.g. the percentages of total enrollment for each group of participants is slightly different.

HER Participants

HER: Comparison of study & future participants

Household Composition & Life Stage

- Compared to future participants, study participants are less likely to be categorized as Family Mix and Mostly Without Kids and more likely to be categorized as Mostly With Kids
- Compared to future participants, study participants are less likely to be categorized as Family Life and Mature Years and more likely to be categorized as Younger Years

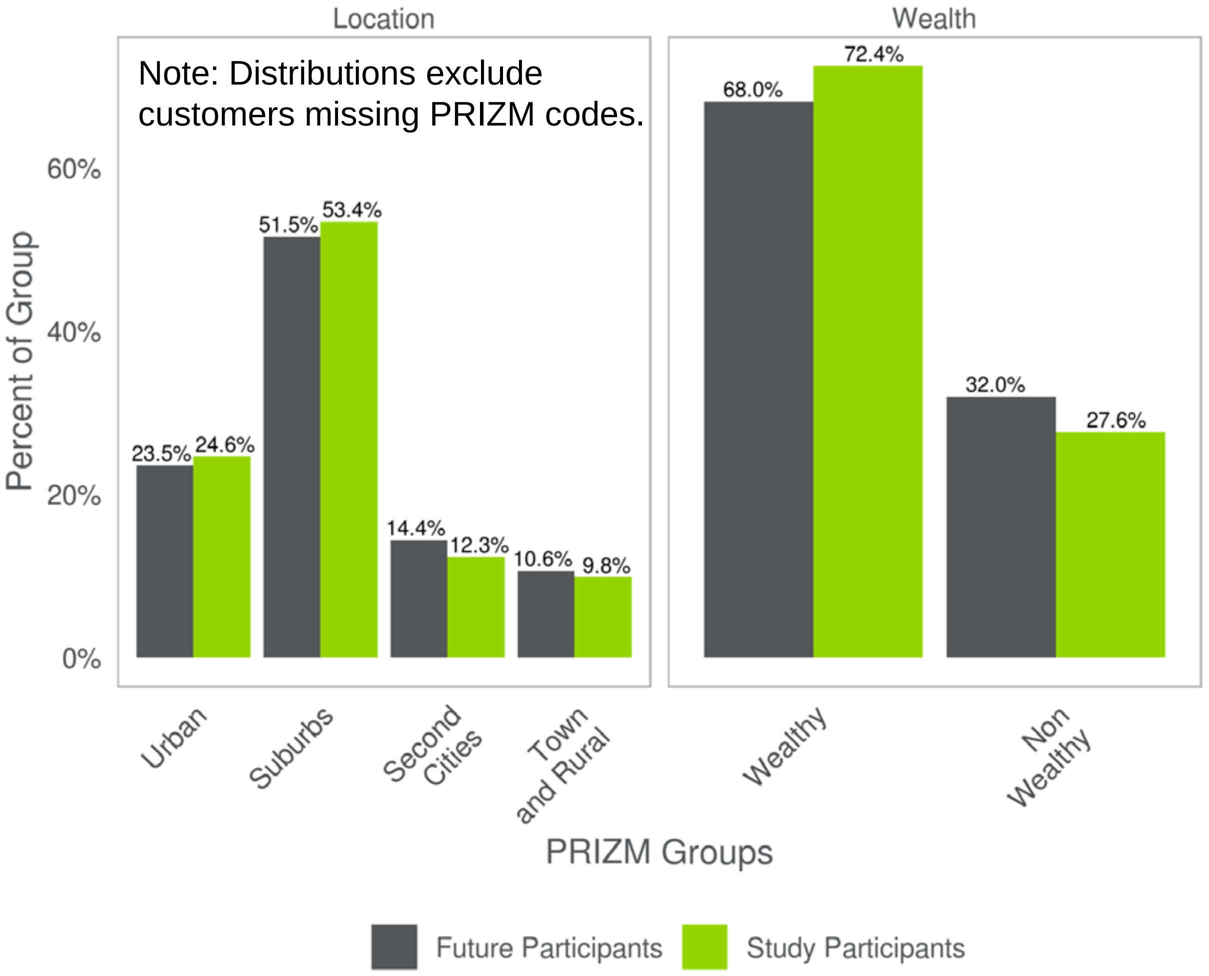


HER Participants

HER: Comparison of study & future participants

Location & Wealth

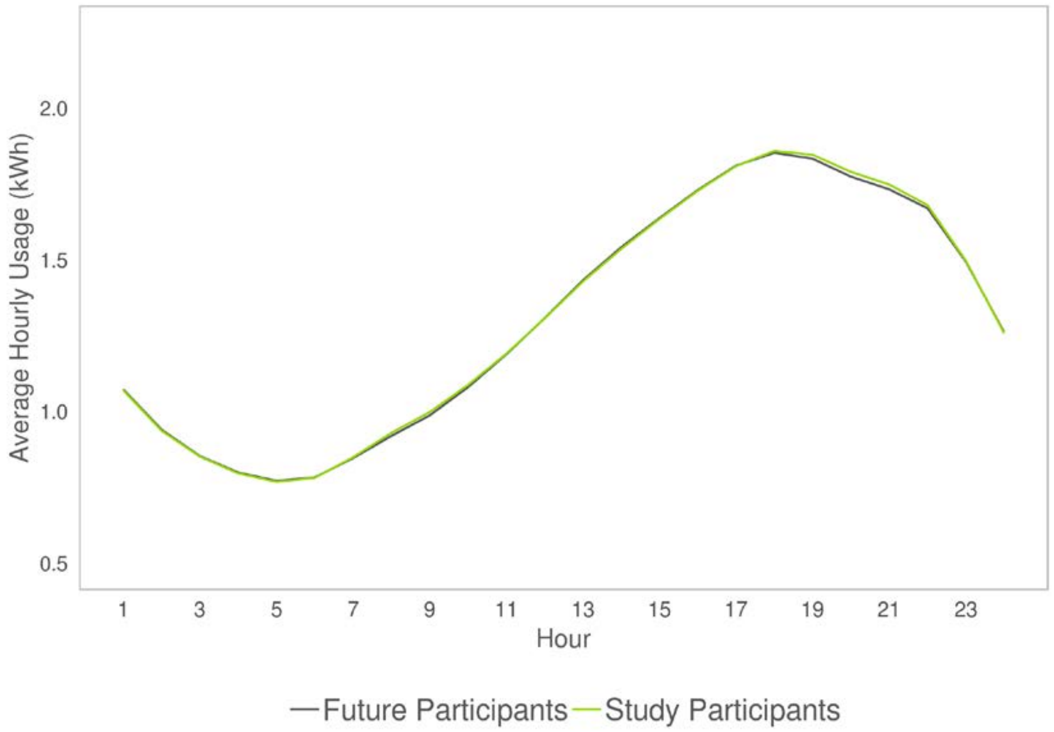
- Compared to future participants, study participants are less likely to be categorized as Second Cities and Town and Rural and more likely to be categorized as Urban and Suburban
- Compared to future participants, study participants are more likely to be categorized as Wealthy

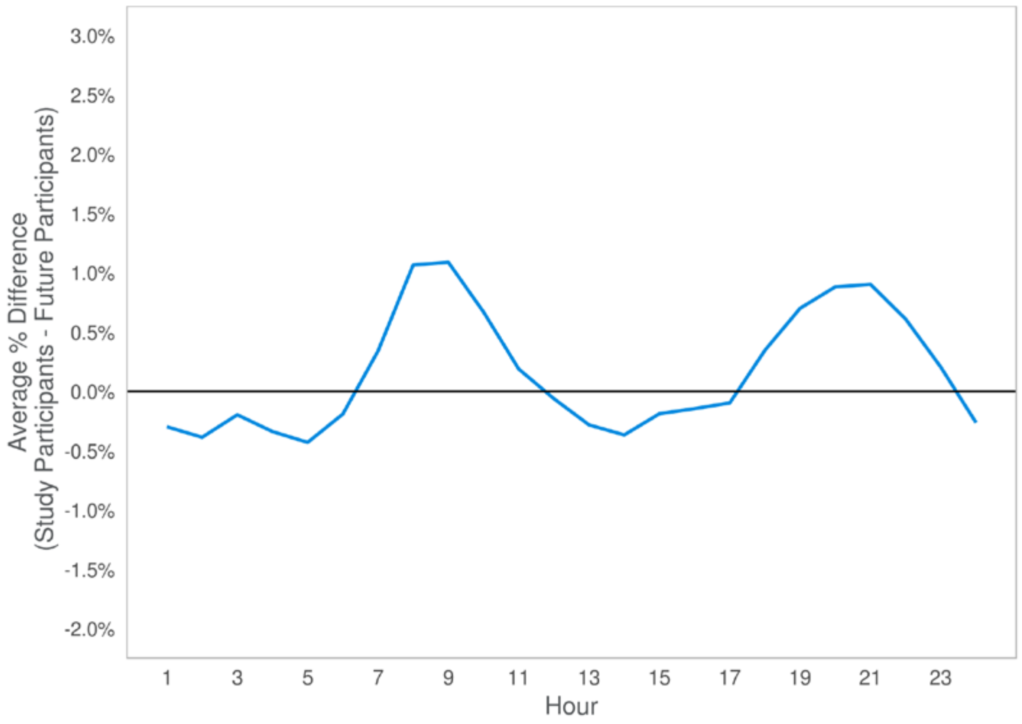


HER: Comparison of study & future participants

Hourly Load Shapes in Pre-Rebate Summer

- In general, study and future participants who are enrolled in the HER program have similar average load shapes during the pre-rebate summer, with absolute differences less than 1.5% in all hours.
- Compared to future participants, study participants have slightly higher usage in the morning and evening hours (7-9 AM, 6-11 PM).





HER Participants

Appendix: Econometric Analysis – Matching Methodology

Guidehouse

Overview

- While Guidehouse concluded that future participants serve as a high-quality comparison group without matching, we additionally explored several matching methods detailed on the next slide.
- Matching may further reduce differences between study participants and the comparison group, to improve its quality. However, Guidehouse found that exact matching on HER wave and demographics reduced the quality of the matches in terms of pre-period energy usage.
- Matching methods ***are used as a pre-processing step for the regression analysis***, which controls for remaining differences as best as possible.
  – While Guidehouse prefers using all future participants as a comparison group without matching (as this results in the most similar energy usage between the study participants and the comparison group), this report includes regression results for each of the matched comparison groups detailed on the next slide.
- The following matching results include all participants (HER and non-HER).
  – The final analysis analyzed HER participants separately from HER non-participants. Match quality for these subgroups are shown later in this section.

Matching Methodology

Guidehouse employed a two-staged matching process.

Step 1: Exact Matching on Demographic Variables

Group A

- HER Wave (Participants are grouped by waves launched before, during, and after the installation period. All HER controls and non-participants form another group.)

Group B

- HER Wave
- PRIZM: Household Composition, Lifestage, Location, Wealth

Group C

- HER Wave
- PRIZM: Lifestage & Wealth

Step 2: Distance Matching on Pre-Installation Usage

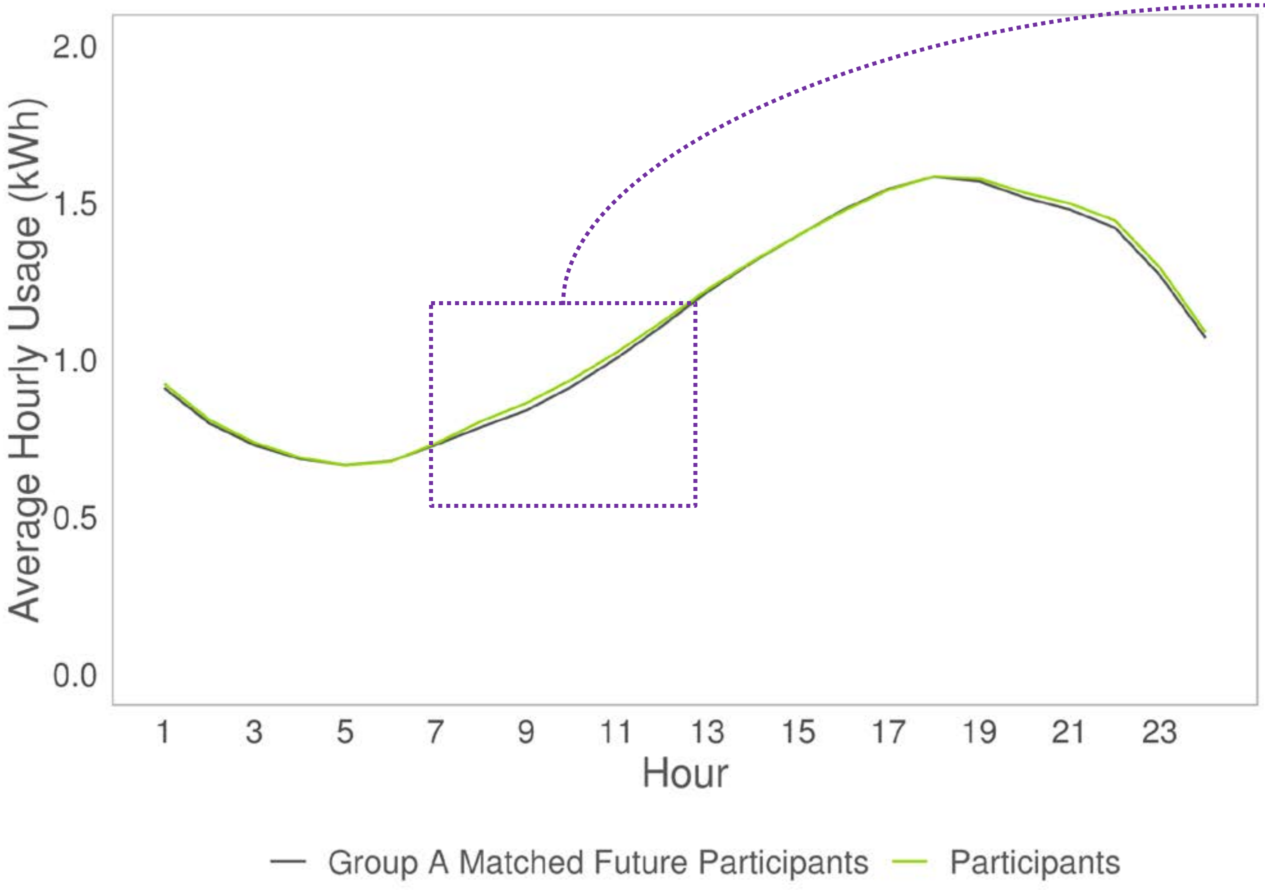
Euclidean Distance

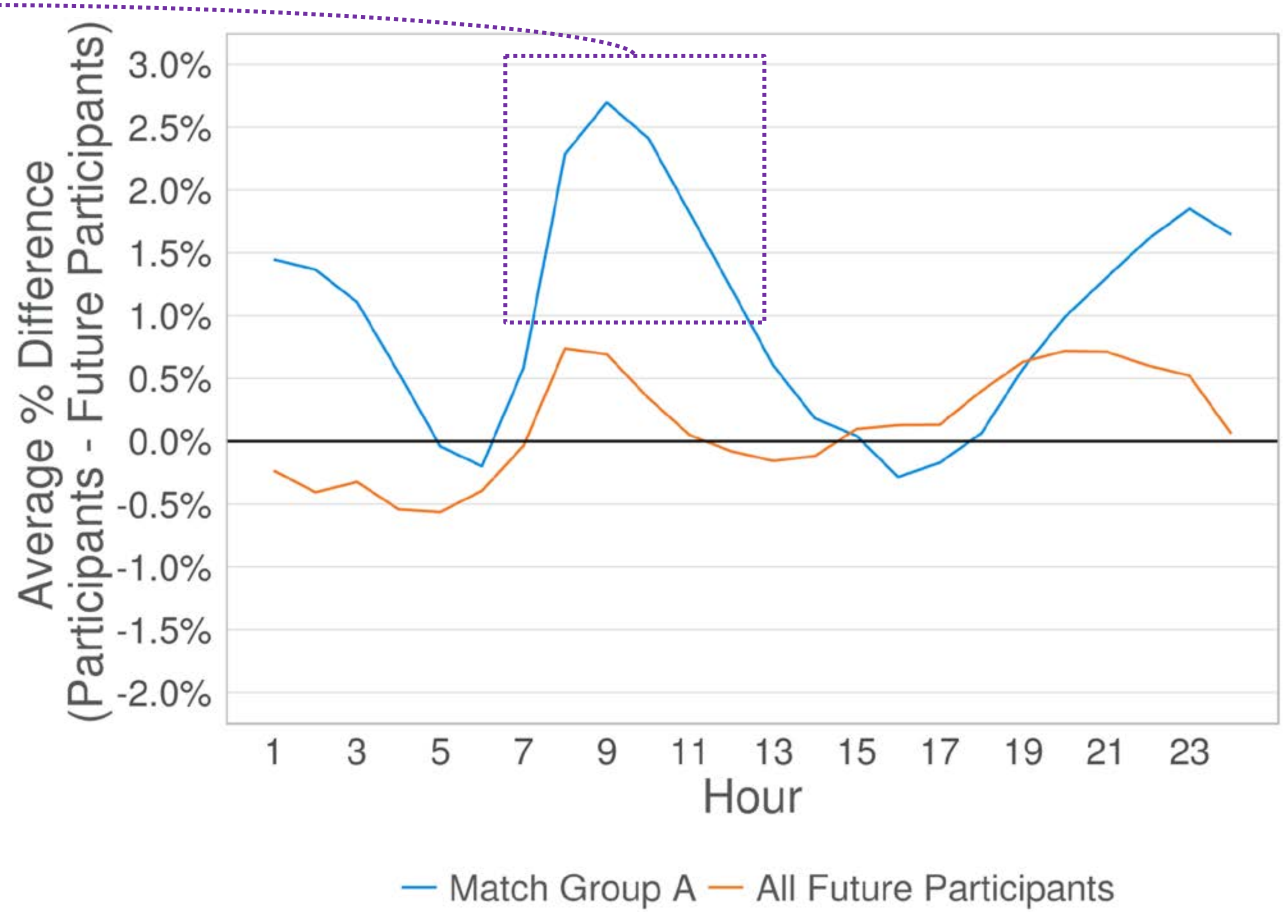
- For each summer month (May to September)
- Average hourly usage by hour bucket (Weekday 8 AM – 5 PM, Weekday 5-9 PM, Weekday 9 PM – 8 AM, Weekend)

Hourly Load Shapes in Pre-Rebate Period

Group A Matches (HER Group, Energy Usage)

- Larger deviations are present in the load shapes for study participants and their matches compared to all future participants. Differences exceed 2% in the mid-morning hours.



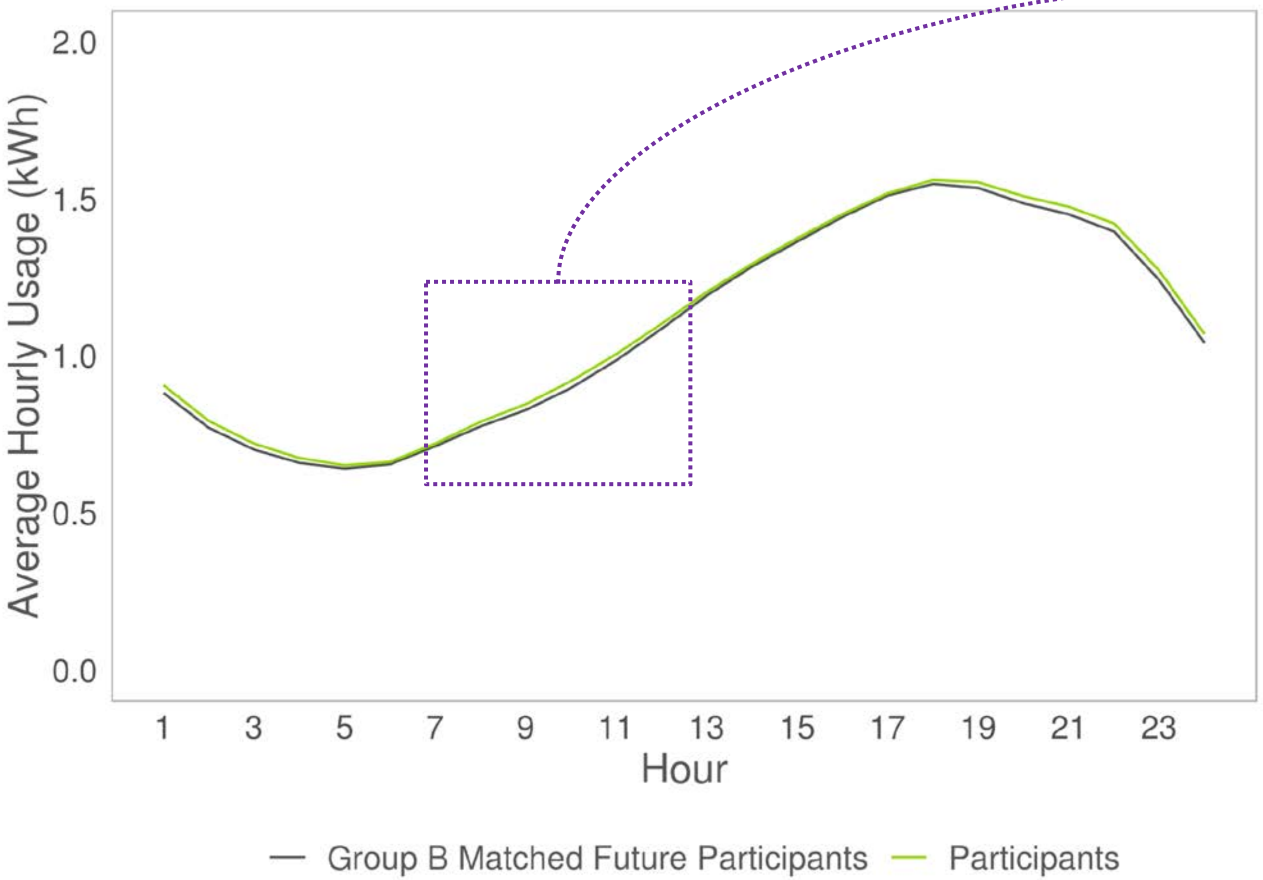


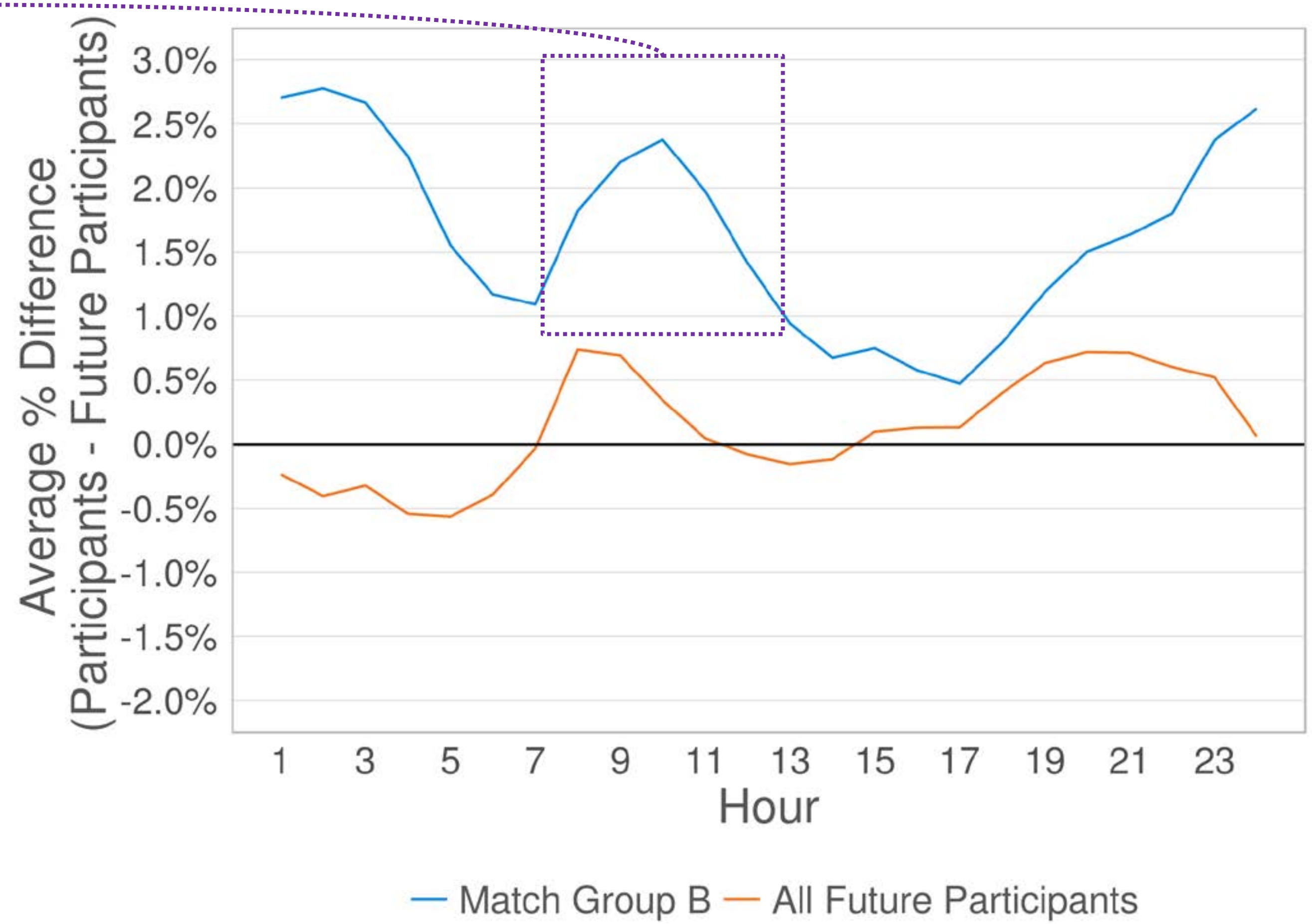
Includes HER & Non-HER

Hourly Load Shapes in Pre-Rebate Period

Group B Matches (HER Group, 4 PRIZM Groups, Energy Usage)

- Larger deviations are present in the load shapes for study participants and their matches compared to all future participants. Differences exceed 2% in the mid-morning and overnight hours. Average usage of study participants exceeds that of their matches in every hour.



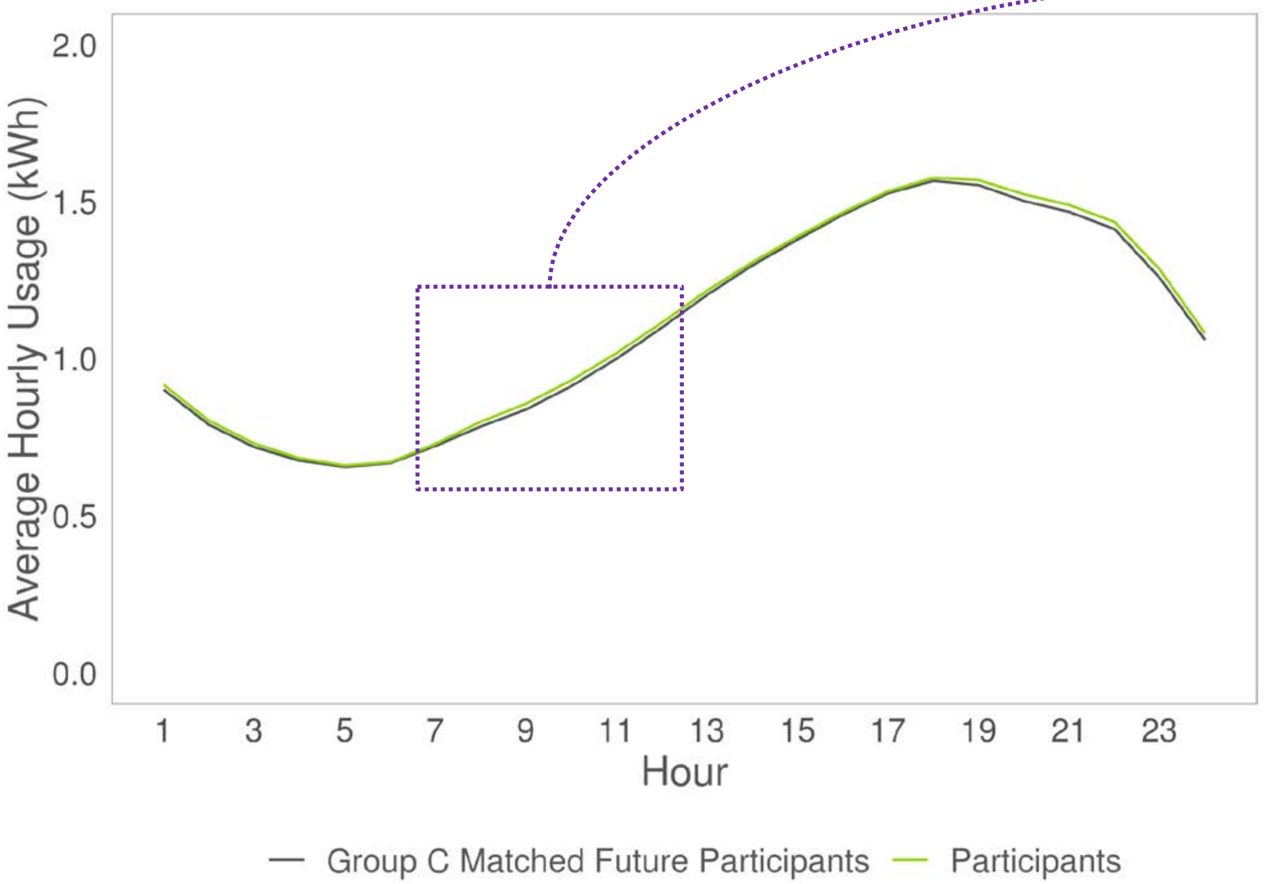


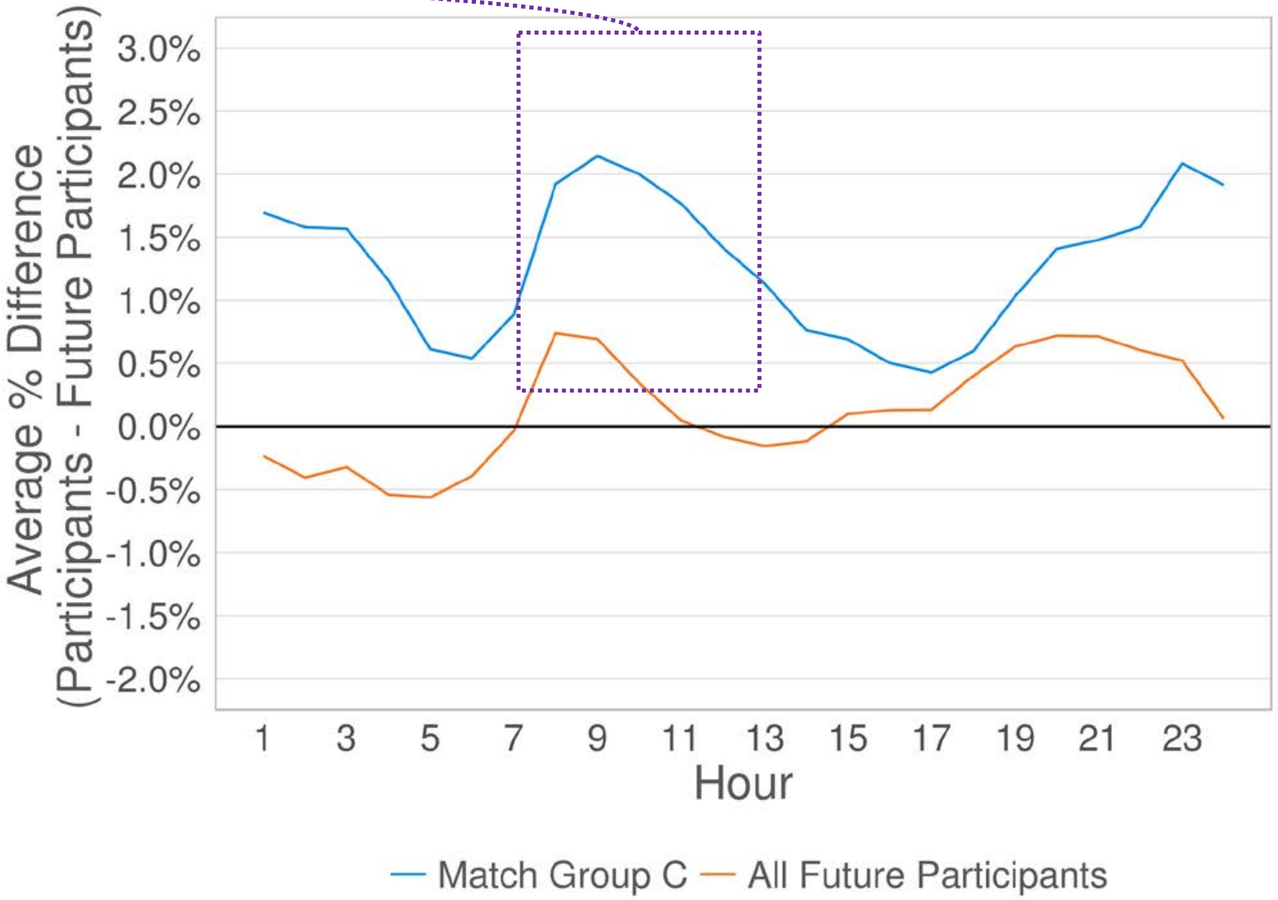
Includes HER & Non-HER

Hourly Load Shapes in Pre-Rebate Period

Group C Matches (HER Group, 2 PRIZM Groups, Energy Usage)

- Larger deviations are present in the load shapes for study participants and their matches compared to all future participants. Differences exceed 2% in the mid-morning hours. Average usage of study participants exceeds that of their matches in every hour.

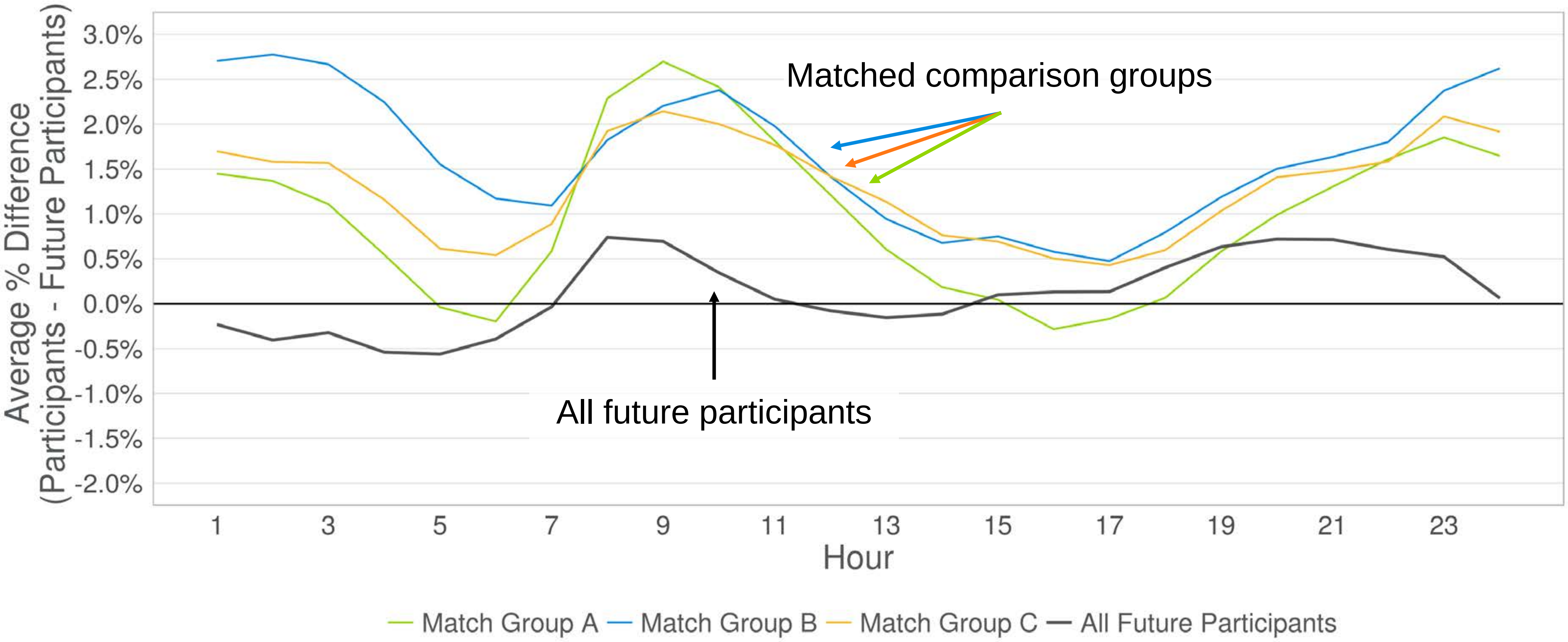




Includes HER & Non-HER

Hourly Load Shapes in Pre-Rebate Period

Although matching reduced the differences in usage between study participants and their Group A matches during the late-afternoon hours, differences are exacerbated in all other hours. Matches from Groups B & C are lower in quality.

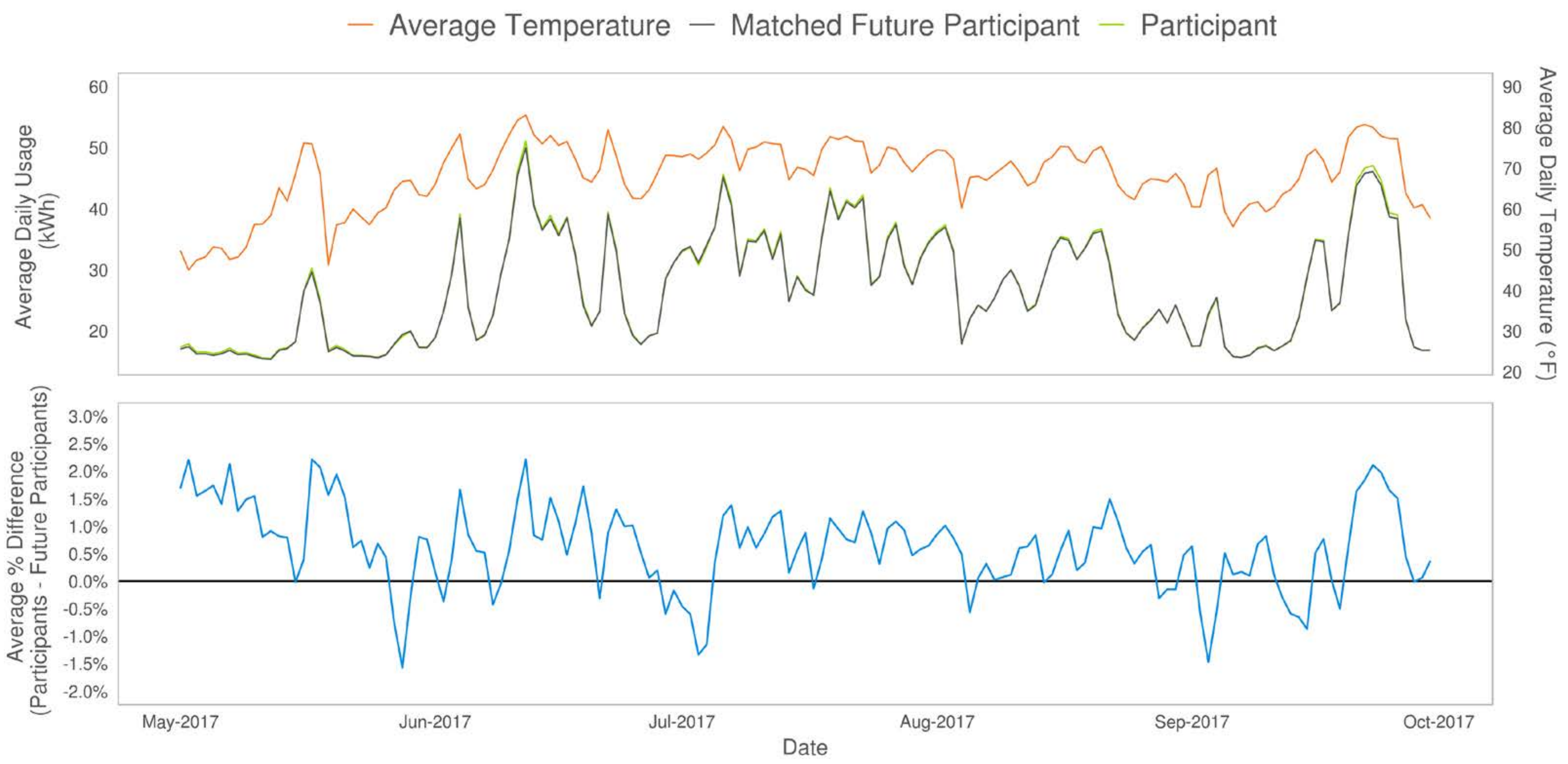


Includes HER & Non-HER

Daily Usage in Pre-Rebate Period

Group A Matches (HER Group, Energy Usage)

- Larger deviations are present in pre-rebate usage patterns for study participants and their matches compared to all future participants.
- Discrepancies in excess of 1% persist throughout the summer.
- Discrepancies exceed 2% on both cool and hot days in May and September

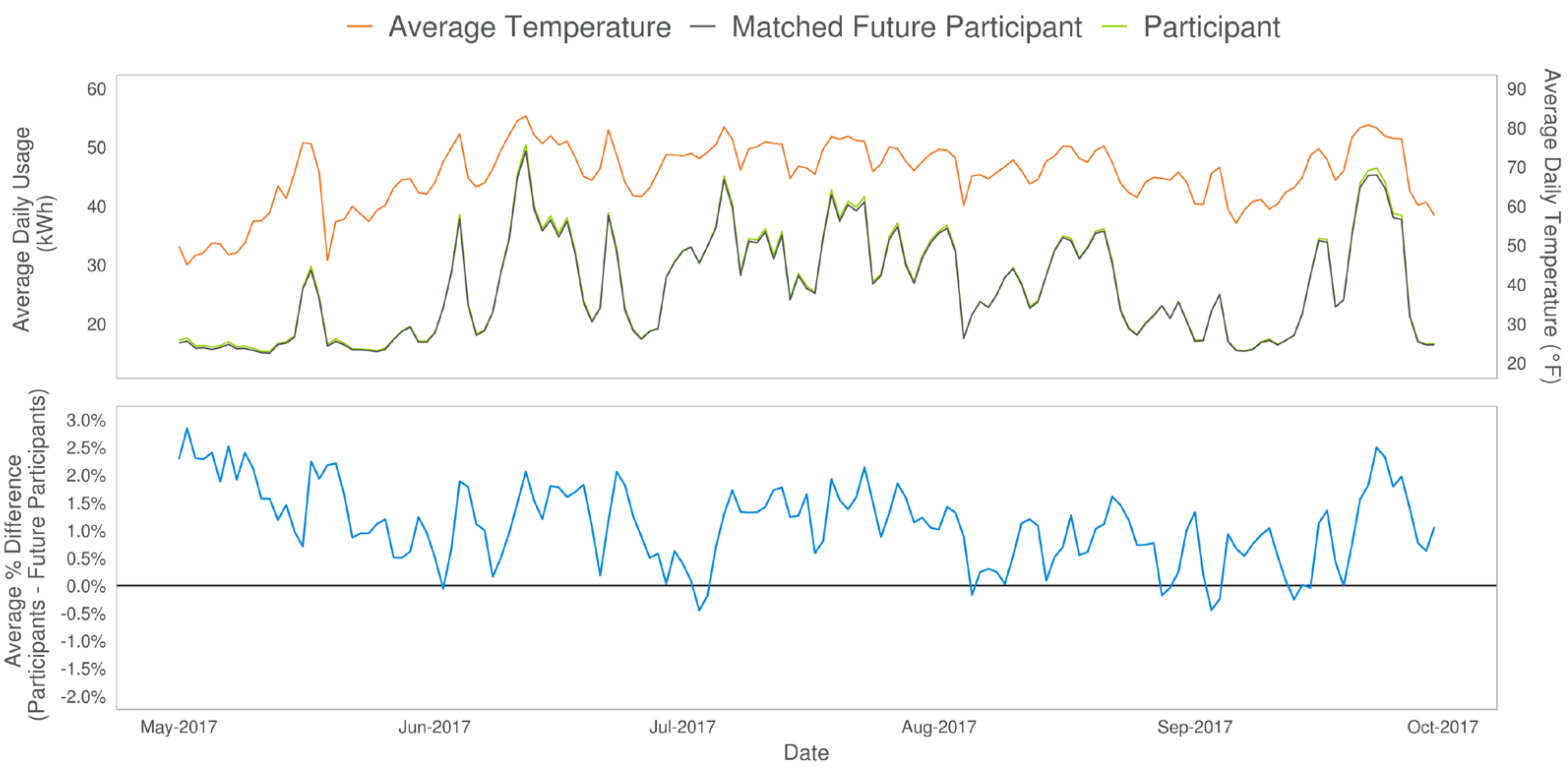


Includes HER & Non-HER

Daily Usage in Pre-Rebate Period

Group B Matches (HER Group, 4 PRIZM Groups, Energy Usage)

- Larger deviations are present in pre-rebate usage patterns for study participants and their matches compared to all future participants.
- Discrepancies in excess of 1.5% persist throughout the summer.
- Average usage of study participants exceeds that of their matches on all but a few days.

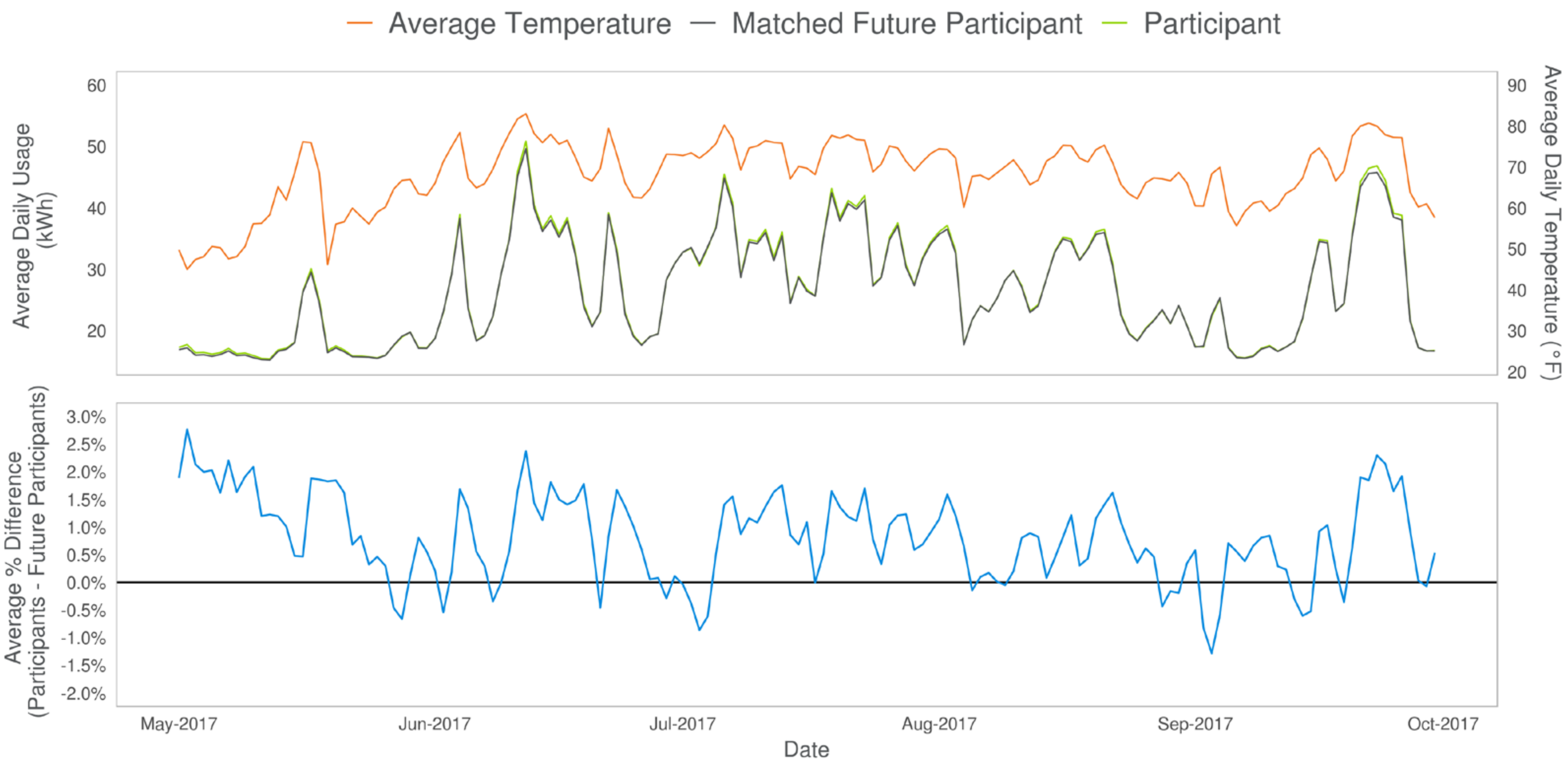


Includes HER & Non-HER

Daily Usage in Pre-Rebate Period

Group C Matches (HER Group, 2 PRIZM Groups, Energy Usage)

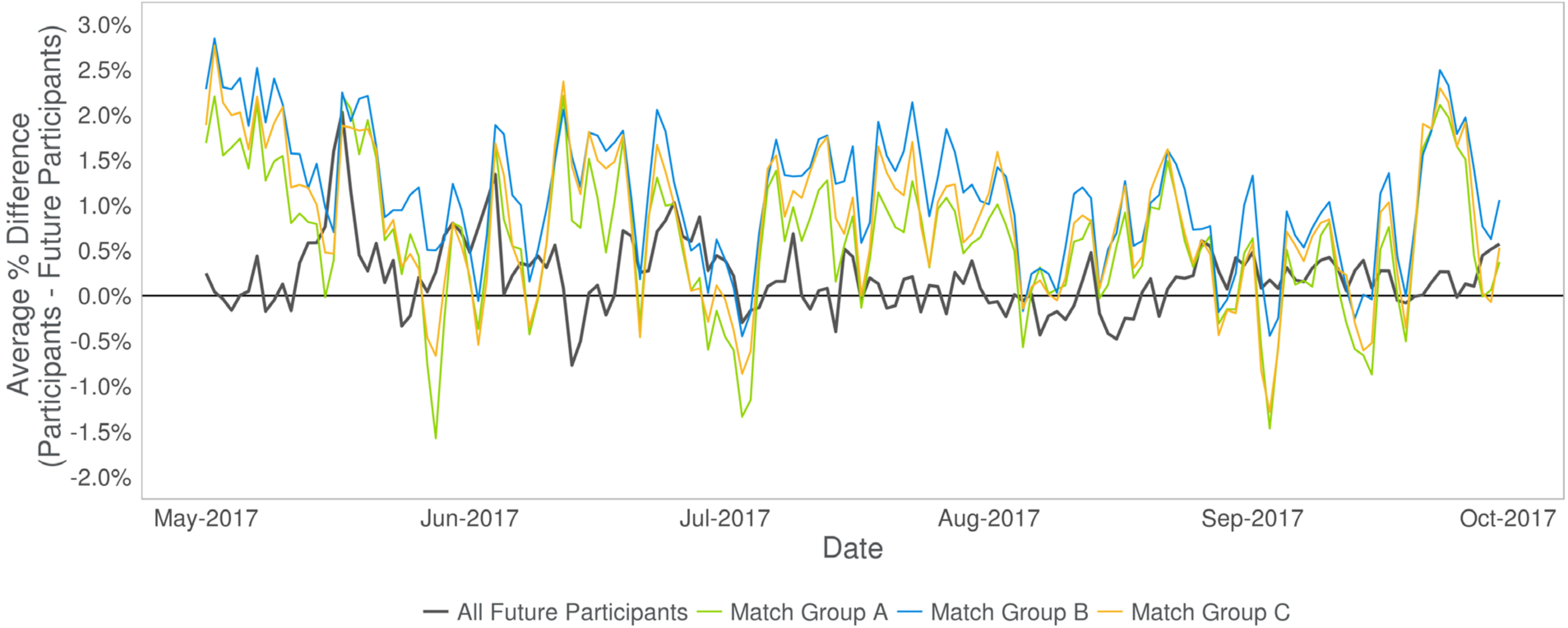
- Larger deviations are present in pre-rebate usage patterns for study participants and their matches compared to all future participants.
- Discrepancies in excess of 1.5% persist throughout the summer.
- Average usage of study participants exceeds that of their matches on most days.



Includes HER & Non-HER

Daily Usage in Pre-Rebate Period

The matching groups exacerbated the differences between study participants and their matches during most days in the pre-rebate summer. Average usage of study participants exceeds that of their matches on all but a few days.



Includes HER & Non-HER

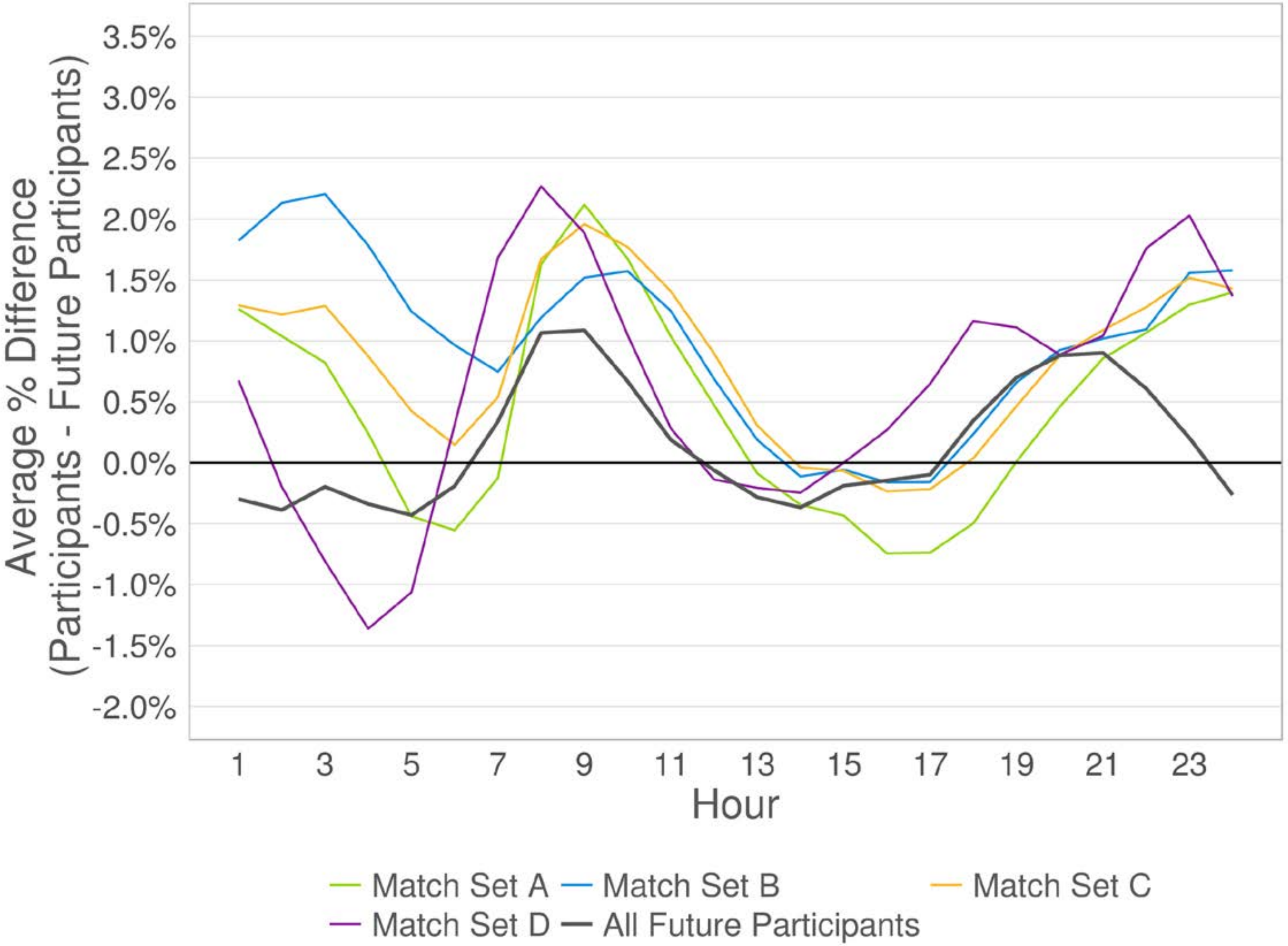
Summary

- Although the matching groups tested force study and future participants to perfectly align on exact matching variables (such as HER group and demographics), they increase the differences in usage patterns during the pre-installation summer compared to using all future participants as the comparison group.
  - Guidehouse concluded that future participants serve as a high-quality comparison group, and further refinements via matching are not required.
  - Guidehouse examined an alternate grouping of hours used for matching, which exacerbated differences in usage patterns during the pre-installation period.
    - Alternate hour buckets for matching: Weekday midnight-5 AM, Weekday 5-10 AM, Weekday 10 AM-6 PM, Weekday 6 PM-midnight, Weekend
  - Guidehouse examined matching on energy usage only. The matches exacerbated differences in demographic variables, which was a particular stakeholder concern.
- While assessing sensitivity of model results to various analysis decisions (including the customer set, model specification, and time of day), Guidehouse discovered that the results varied substantially for HER participants and HER non-participants. As a result, Guidehouse re-examined the match quality for each of these subgroups (HER participants and HER non-participants). Study and future participants are well-balanced for HER participants. Guidehouse was unable to form a matched comparison group for HER non-participants that was of sufficient quality.
  - The following slides show match quality for HER participants and HER non-participants.

HER: Hourly Load Shapes in Pre-Rebate Period

Hourly Load Shapes in Pre-Rebate Summer

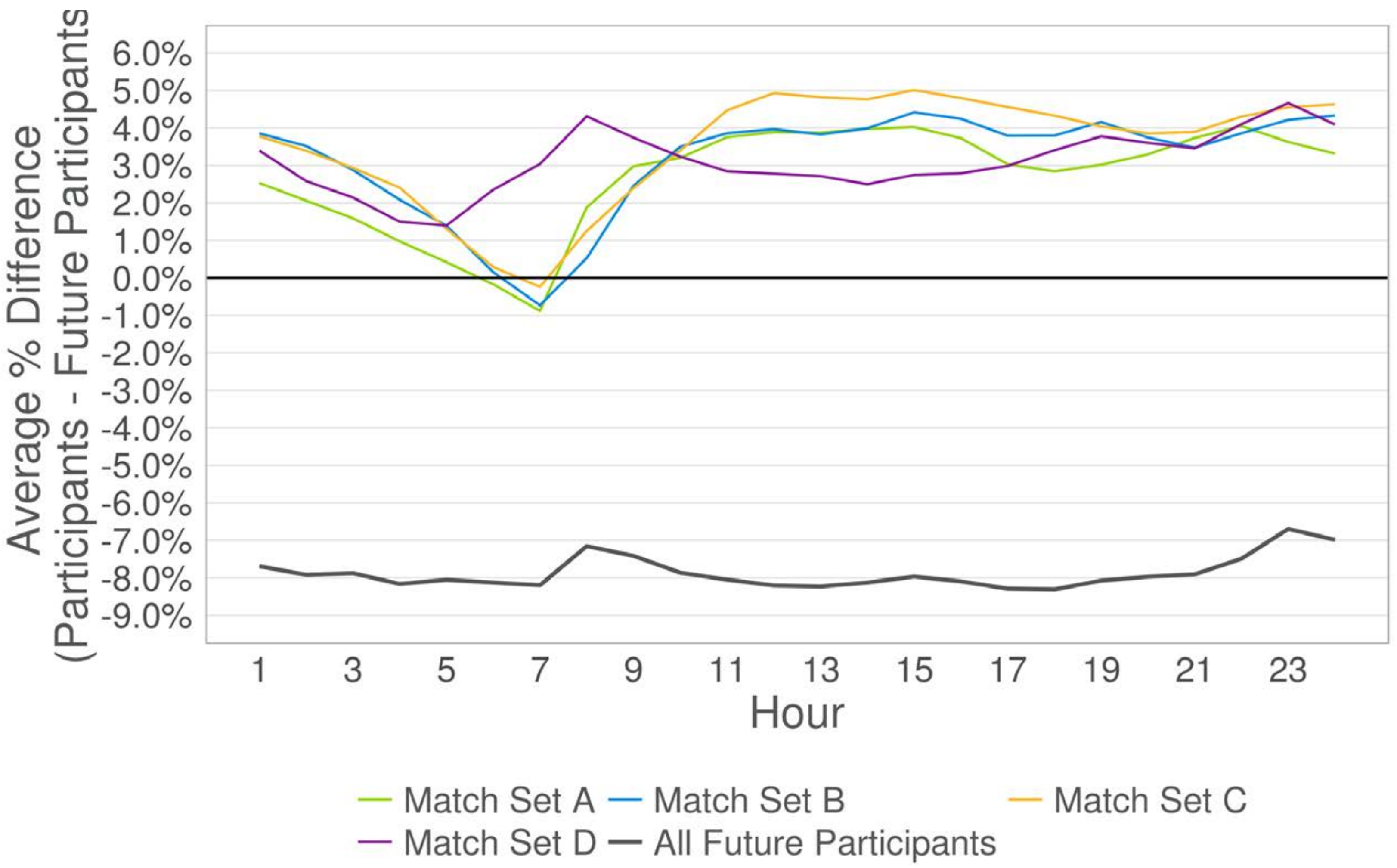
- Although some of the match sets reduce the difference between study participants and their matches in some hours, differences are larger in other hours. Guidehouse used all future participants as the comparison group.
- Study and future participants who are enrolled in the HER program are well balanced with respect to usage in the pre-rebate summer and demographic characteristics. Further refinements via matching were not required.



Non-HER: Hourly Load Shapes in Pre-Rebate Period

Hourly Load Shapes in Pre-Rebate Summer

- All future participants are shown in gray and showed large differences from the study participants. Guidehouse tried various matching schema to bring them closer, but ultimately concluded that a comparison group of sufficient quality could not be found with the available data.
- All match sets employ calipers, which exclude matched pairs with Euclidean distances greater than 0.75-0.90 (varies by match set). Calipers remove up to 38% of matched pairs.
- Although matching reduced the difference in usage patterns between participants and the comparison group, none of these match sets were of sufficient quality for Guidehouse to feel comfortable recommending savings based on them.



Appendix: Econometric Analysis – Estimating Savings

Guidehouse

Stakeholder Feedback on Regression Modeling

Summary of comments in addressed in this study

Guidehouse made multiple changes to this research compared to our PY9 research, based on stakeholder feedback.

Theme	Comments	Evaluators' Actions to Address Issue
Suggestions for Changes to Model Specifications	• Include un-interacted treatment variables (i.e. non-weather-dependent treatment effects) • Interact all variables (e.g. demographic variables) with hourly terms (or model each hour individually); demographic terms are expected to impact load shapes • Use a lagged temperature variable within the LDV specification • Include customer fixed-effects to account for time-invariant customer effects	• Guidehouse revised model specifications to incorporate stakeholder feedback within the data and time constraints available for analysis • Guidehouse utilized daily usage data for estimating savings (as opposed to monthly data used in the previous analysis).
Test Sensitivity of Estimates to Different Models	• Simple difference-in-difference model • Models with and without weather variables included • Separate hourly models for different day types • Fixed-effects model for comparison with the LDV model • Within-subject (participants only) model	• Guidehouse tested sensitivity to a number of different model types in order to assess the robustness of savings estimates.

Stakeholder Feedback on Regression Modeling

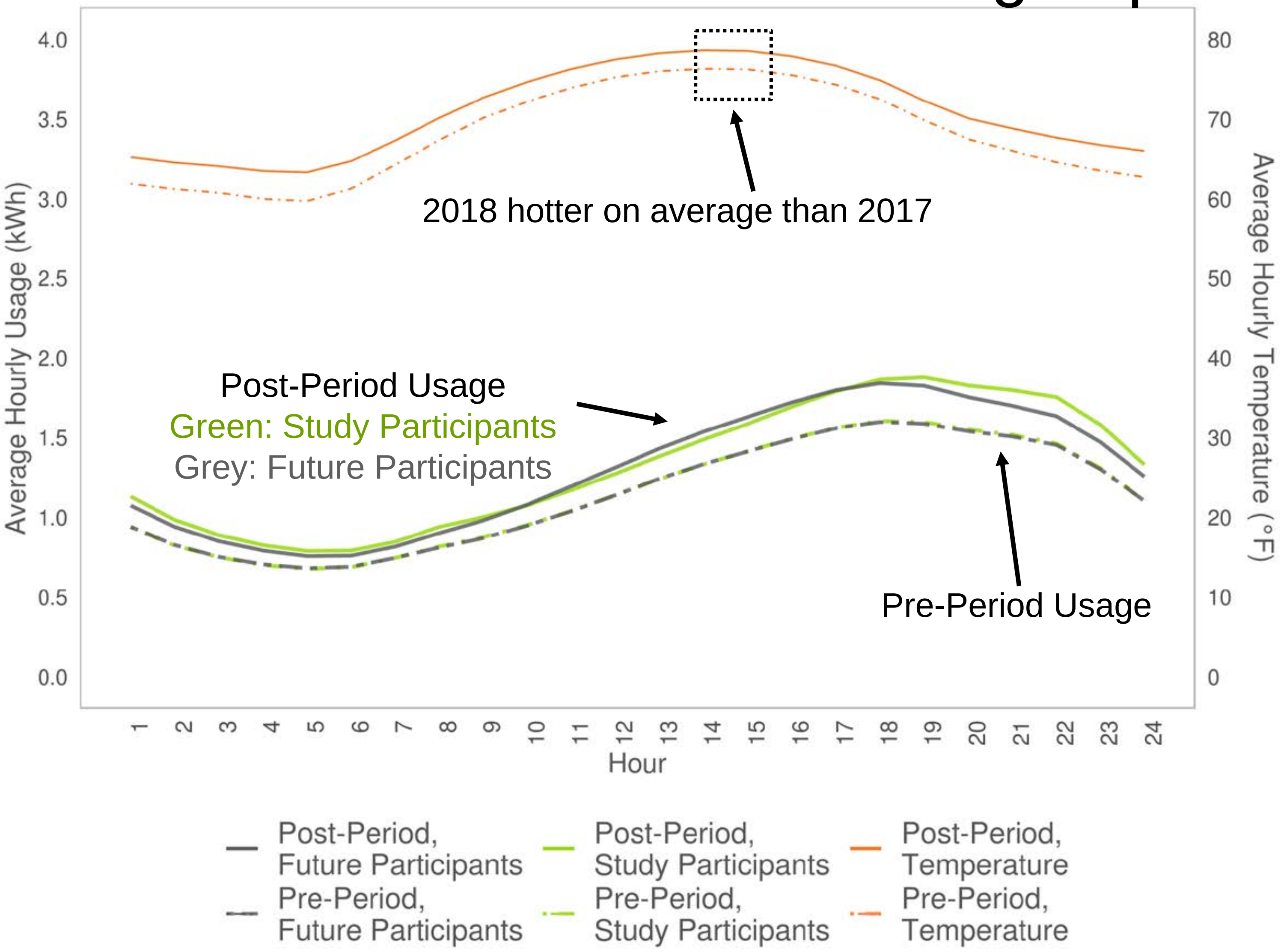
Summary of comments in addressed in the current study

Theme	Comments	Evaluators' Actions to Address Issue
Estimation of Cooling Load	• Unclear how analysis will estimate cooling load and percentage cooling savings. • Previously proposed model may not estimate hourly cooling load accurately.	• Guidehouse used the aggregate thermostat telemetry data to estimate cooling load.
Use AMI data to investigate potential selection bias	• Determine which changes in usage are attributable to smart thermostats and which are unrelated. • Previous analyses were interpreted to be attributing changes in apparent baseload to smart thermostats.	• Guidehouse used AMI data to explore load shapes for different customer segments before and after installation of a smart thermostat, as well as for future participants who did not install a device in the study period. • Guidehouse used AMI data to investigate match quality (e.g. comparing hourly load shapes).

Comparison of pre- and post-installation load shapes

Usage increased from summer 2017 to summer 2018 for both groups

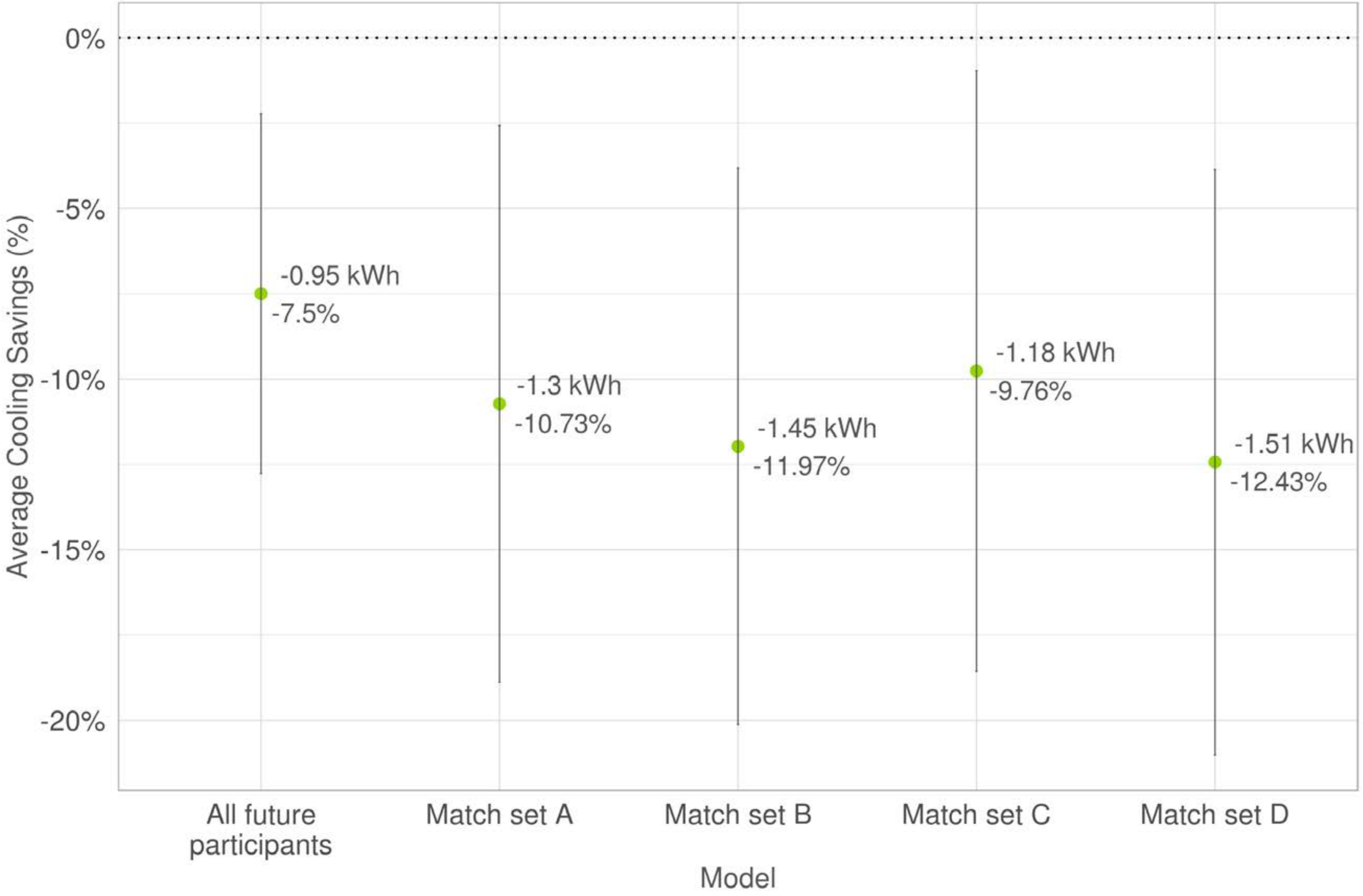
- Usage increased from summer 2017 to summer 2018 for both study and future participants.
  - 9.3% average daily use increase for study participants
  - 9.1% average daily use increase for future participants
- Much of this increase can be attributed to differences in weather. On average, summer 2018 was hotter than summer 2017.
- Given the upward trend in usage, Guidehouse recommends regression models that include a comparison group.
  - Note that any models Guidehouse runs using a comparison group incorporate both pre and post data.



Savings Estimates: HER non-participants

Results were not sensitive to the different comparison groups tested.

- **Guidehouse does not recommend using these values, due to low-quality matches.**
- Match Set A, B, & C employ exact matching on customer characteristics, followed by Euclidean distance matching on hour buckets
  - Set A: HER non-participants
  - Set B: HER non-participants + four PRIZM groups
  - Set C: HER non-participants + two PRIZM groups
- Match group D does not match on customer characteristics. Matches are selected based on Euclidean distance over a 24-hr load shape for weekdays and weekends.
- Savings are calculated using 2018 observed weather and the LDV model.



Lagged Dependent Variable (LDV)

Preferred Model

$$y_{i,t} = \sum_{m=5}^{9} \beta_{m,1} \cdot month_{t,m} + \sum_{m=5}^{9} \beta_{m,2} \cdot month_{t,m} \cdot weekendhol_t$$

$$+ \sum_{d=1}^{7} \sum_{m=5}^{9} \beta_{m,3} \cdot month_{t,m} \cdot prekWh_{i,t,d} + \beta_4 \cdot CDD_{i,t} + \beta_5 \cdot weekendhol_t \cdot CDD_{i,t}$$

$$+ \boldsymbol{\gamma_1} \cdot \boldsymbol{treat_i} + \boldsymbol{\gamma_2} \cdot \boldsymbol{weekendhol_t} \cdot \boldsymbol{treat_i}$$

$$+ \boldsymbol{\gamma_3} \cdot \boldsymbol{CDD_{i,t}} \cdot \boldsymbol{treat_i} + \boldsymbol{\gamma_4} \cdot \boldsymbol{CDD_{i,t}} \cdot \boldsymbol{weekendhol_t} \cdot \boldsymbol{treat_i}$$

$$+ \sum \delta \cdot Demographics_i$$

$$+ \epsilon_{i,t}$$

- $prekWh$ is the average usage from the pre-rebate period for the month and weekday corresponding to the observation.
- $Demographics$ include HER wave, ZIP code, PRIZM code, property type (single- or multi-family), HVAC type, and existing thermostat type.
- Additional variable definitions appear on the next slide.
- Standard errors are clustered at the customer level.
- **Savings** are allowed to vary by weekend/holiday vs. weekday and by CDD.

Additional Regression Variable Definitions

- $month$ is a binary variable taking a value of 1 for the month corresponding to the observation and 0 otherwise.
- $weekendhol$ is a binary variable taking a value of 1 if the observation occurs on a weekend or holiday and 0 otherwise.
- CDD is the cooling degree days, calculated from the average daily temperature, with a base of 65ºF.
- $treat$ is a binary variable taking a value of 1 for study participants and 0 for future participants.
- $post$ is a binary variable taking a value of 1 if the observation occurs during the post-rebate period (summer 2018) and 0 otherwise.

Fixed Effects (FE), with daily fixed effects

Robustness check

$$
\begin{aligned}
y_{it} = {} & \alpha_i + \delta_t \\
& + \beta_1 \cdot CDD_{it} + \beta_2 \cdot CDD_{it} \cdot wkendhol_t \\
& + \beta_3 \cdot CDD_{it} \cdot post_t + \beta_4 \cdot CDD_{it} \cdot wkendhol_t \cdot post_t \\
& + \beta_5 \cdot CDD_{it} \cdot treat_i + \beta_6 \cdot CDD_{it} \cdot wkendhol_t \cdot treat_i \\
& + \beta_7 \cdot HERpost_t \\
& + \boldsymbol{\gamma_1} \cdot \boldsymbol{treat_i} \cdot \boldsymbol{post_t} + \boldsymbol{\gamma_2} \cdot \boldsymbol{treat_i} \cdot \boldsymbol{post_t} \cdot \boldsymbol{wkendhol_t} \\
& + \boldsymbol{\gamma_3} \cdot \boldsymbol{treat_i} \cdot \boldsymbol{post_t} \cdot \boldsymbol{CDD_{it}} + \boldsymbol{\gamma_4} \cdot \boldsymbol{treat_i} \cdot \boldsymbol{post_t} \cdot \boldsymbol{wkendhol_t} \cdot \boldsymbol{CDD_{it}} \\
& + \epsilon_{i,t}
\end{aligned}
$$

- Includes customer and daily fixed effects.
- Standard errors are clustered at the customer level.
- Additional variables definitions appear on previous slide.
- **Savings** are allowed to vary by weekend vs. weekday and by CDD.

Fixed Effects (FE), without daily fixed effects

Robustness check, similar to PY9 model specification

$$
\begin{aligned}
y_{it} = {} & \alpha_i \\
& + \beta_1 \cdot CDD_{it} + \beta_2 \cdot post_t \\
& + \beta_3 \cdot CDD_{it} \cdot post_t + \beta_4 \cdot CDD_{it} \cdot treat_i \\
& + \beta_5 \cdot HERpost_t \\
& + \boldsymbol{\gamma_1 \cdot treat_i \cdot post_t + \gamma_2 \cdot treat_i \cdot post_t \cdot CDD_{it}} \\
& + \epsilon_{i,t}
\end{aligned}
$$

- Includes customer fixed effects.
- Standard errors are clustered at the customer level.
- Additional variables definitions appear on a previous slide.
- **Savings** are allowed to vary by CDD.

Within-Subjects ("Pre-Post")

Robustness check

$$
\begin{aligned}
y_{it} = {} & \alpha_i \\
& + \beta_1 \cdot CDD_{it} + \beta_2 \cdot wkendhol_t + \beta_3 \cdot CDD_{it} \cdot wkendhol_t + \sum \beta_{4m} \cdot Month_t + \beta_5 \cdot HERpost_t \\
& + \boldsymbol{\gamma_1 \cdot post_t + \gamma_2 \cdot post_t \cdot CDD_{it} + \gamma_3 \cdot post_t \cdot wkendhol_t} \\
& + \boldsymbol{\gamma_4 \cdot post_t \cdot CDD_{it} \cdot wkendhol_t} \\
& + \epsilon_{i,t}
\end{aligned}
$$

- Includes customer fixed effects.
- Standard errors are clustered at the customer level.
- **Savings** are allowed to vary by weekend vs. weekday and by CDD.
- Model is estimated separately for study participants and future participants.
  - Future participants are expected to produce zero savings and are estimated as a check on the specification.

Appendix: Econometric Analysis – Estimating Cooling Load

Guidehouse

Estimating Cooling Load Savings

Overview

- The results of the econometric analysis are intended to support updating the Cooling Reduction factor in the IL TRM equation, which is savings as a percentage of cooling load.
- Since the econometric analysis produces an estimate of whole home energy savings, Guidehouse needed an estimate of cooling load to develop an estimate of percentage cooling savings.

From IL-TRM Version 8.0 Volume 3: Residential Measures, Section 5.3.16 Advanced Thermostats, p. 167:

$$\Delta kWh_{cool} = \%AC \times \frac{FLH \times Capacity}{SEER \times 1000} \times Cooling\_Reduction \times Eff\_ISR$$

Energy Savings, from econometric analysis → ΔkWh_{cool}

% of Customers with Thermostat-Controlled AC → $\%AC$

Assumed Annual Energy Consumption → $\frac{FLH \times Capacity}{SEER \times 1000}$

Derive Percentage Cooling Energy Savings → $Cooling\_Reduction$

Effective In-Service Rate → Eff_ISR

Estimating Cooling Load Savings

Use IL TRM equation to convert absolute kWh savings to percentage cooling load savings.

Equation from previous slide, solved for Cooling_Reduction

$$Cooling\_Reduction = \frac{\Delta kWh_{cool} \times 1000}{\%AC \times FLH \times Capacity \times \frac{1}{SEER} \times Eff\_ISR}$$

Where:

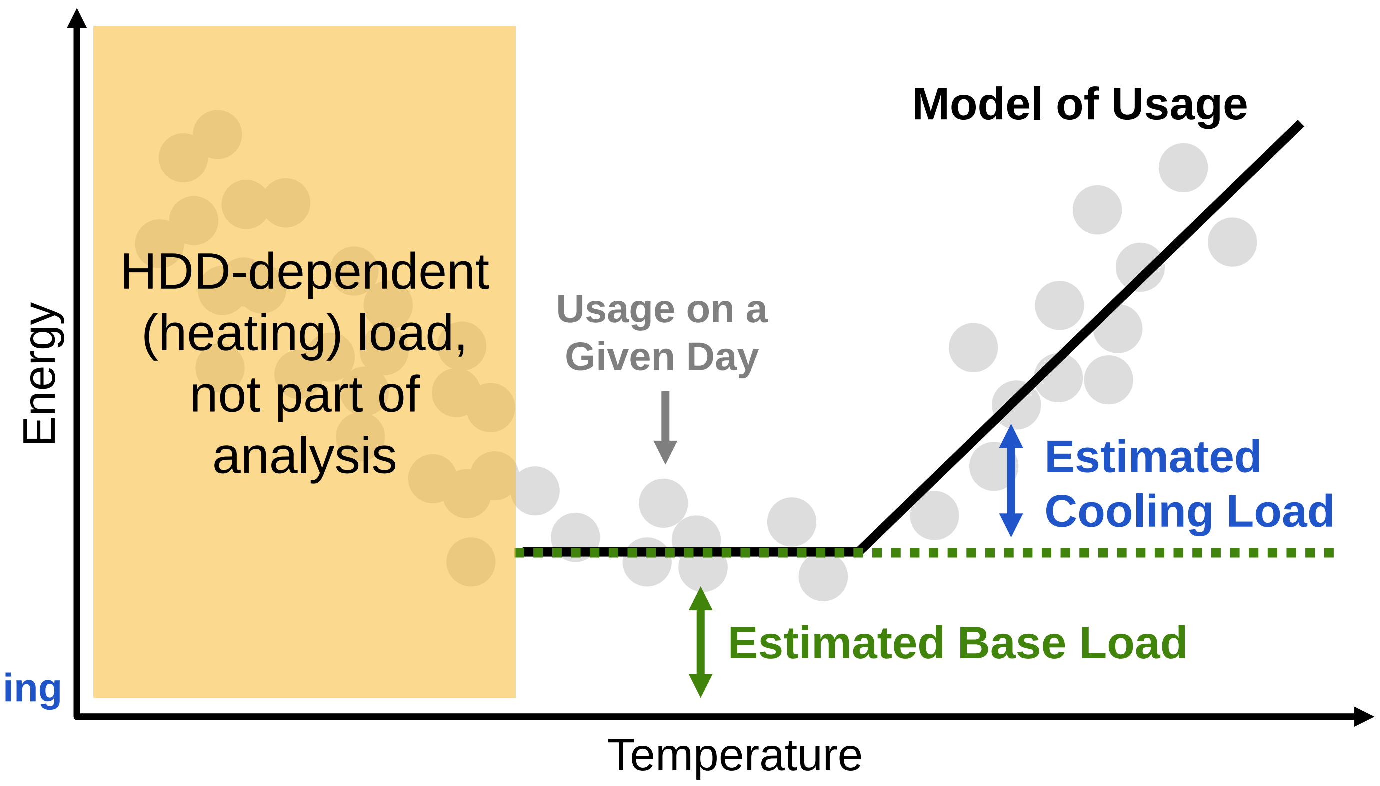
Cooling Reduction	=	average percentage reduction in total household cooling energy consumption due to installation of advanced thermostat
ΔkWh_{cool}	=	average absolute reduction in kWh during cooling season due to installation of advanced thermostat as estimated by regression analysis
%AC	=	99% per IL TRM as ComEd's rebate is an AC targeted program
FLH	=	weighted average full cooling load hours across climate zones for study participants based on table in IL TRM
Capacity	=	average size of AC unit for study participants (Mostly via the IL TRM; exact values only available for participants through the Residential HVAC program)
SEER	=	average Seasonal Energy Efficiency Ratio rating for study participants (12, via stakeholder feeback)
Eff_ISR	=	100% per IL TRM as the effective in-service rate is accounted for in the regression analysis

Guidehouse

Estimating Cooling Load Savings

Regression Analysis (PY9 Model), used as a robustness check.

$$y_{it} = \alpha_i$$
$$+\beta_1 \cdot CDD_{it} + \beta_2 \cdot post_t$$
$$+\beta_3 \cdot CDD_{it} \cdot post_t + \beta_4 \cdot CDD_{it} \cdot treat_i$$
$$+\gamma_1 \cdot treat_i \cdot post_t + \gamma_2 \cdot treat_i \cdot post_t \cdot CDD_{it}$$
$$+\epsilon_{it}$$



- Model used in PY9, used as a robustness check
- Used to estimate counterfactual daily CDD-dependent load, disaggregated from base load
  - **Blue – CDD-dependent consumption; assumed to be cooling consumption**
  - **Green – Treatment effect; not included in order to estimate counterfactual**

$$kWh_{cooling,daily} = \beta_1 \cdot CDD_{avg} + \beta_3 \cdot CDD_{avg} + \beta_4 \cdot CDD_{avg}$$

- Use average CDD for participants over study-period

Estimating Cooling Load Savings

Thermostat Telemetry Data

Guidehouse used the following equation to convert HVAC runtime to electric load.* Since this represents usage after installation of a smart thermostat, Guidehouse added estimated energy savings in order to estimate the counterfactual (pre-installation) load.

$$\widehat{kW}_t = \beta_1 + \beta_2 \cdot \frac{Runtime\ \cdot Q_{AC}}{EER \cdot\ 1{,}000} + \beta_3 \cdot CDH + \beta_4 \cdot CDH \cdot \frac{Runtime\ \cdot Q_{AC}}{EER\ \cdot\ 1{,}000}$$

Where:

- $\widehat{kW}$ is the estimated power draw in period *t*
- $Runtime$ is the amount of time (in hours) during period t where the AC or HP is running
- Q_{AC} is rated AC or HP capacity in Btu / hr. Average of 32,711 from program tracking data (when available) and IL TRM assumptions
- CDH – cooling degree hours (base 70°F)
- EER – Energy Efficiency Ratio = 12 SEER per stakeholder feedback converted to EER (10.65)**
- $\beta_1, \beta_2, \beta_3, \beta_4$: parameters derived from 2017 Massachusetts Baseline Study*

* Conversion of thermostat runtime to power based on an analysis of metering data from the 2017 Massachusetts Baseline Study. See: http://www.iepec.org/2017-proceedings/65243-iepec-1.3717521/t001-1.3718144/f001-1.3718145/a008-1.3718196/an031-1.3718201.html
** Conversion of SEER to EER based on US DOE Building America House Simulation Protocols. See: https://www.nrel.gov/docs/fy11osti/49246.pdf

Appendix: Econometric Analysis – PRIZM Data

PRIZM Data

Guidehouse leveraged ComEd's PRIZM data purchased from Claritas to select a comparison group

- ComEd provided PRIZM codes for participants in the study
- Claritas leverages proprietary data to assign households to one of 68 PRIZM segments.
- Detailed information about each segment is available at: https://claritas360.claritas.com/mybestsegments/#segDetails
- Guidehouse leveraged the following variables assigned to each PRIZM segment when selecting matched controls:
  - Household composition (family mix, mostly with kids, mostly without kids, without kids, unknown)
  - Lifestage (younger years, family life, mature years, unknown)
  - Location (urban, suburbs, second cities, town and rural, unknown)
  - Wealth (wealthy, not wealthy, unknown)

Appendix: Econometric Analysis – Exploratory Analyses

Guidehouse

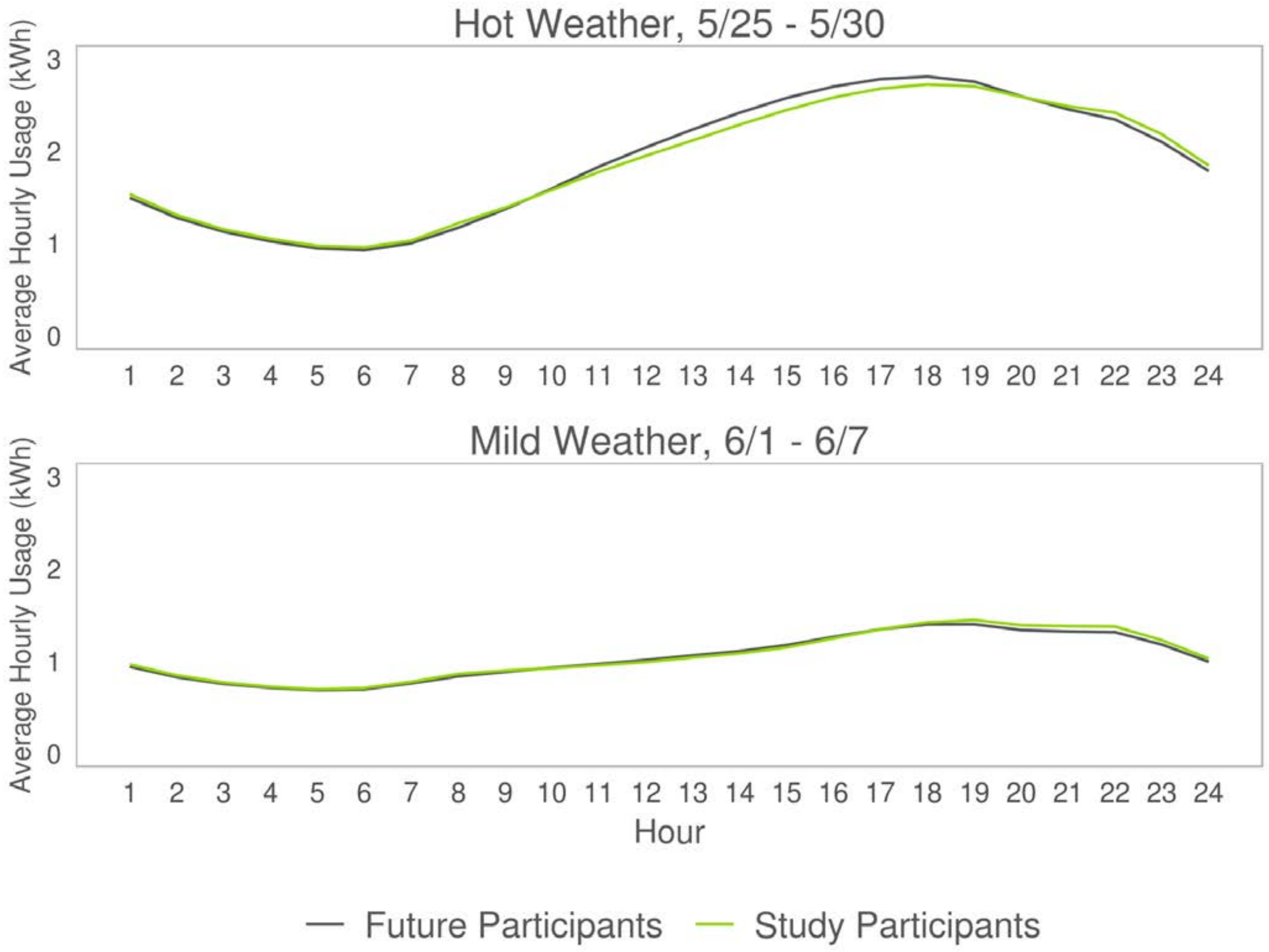
Mild vs Hot Weather Load Shape Comparison (1/2)

Issue

- Do the post-rebate differences in load shapes for study and future participants exist in mild weather conditions?

Findings

- Guidehouse examined load shapes during mild and hot periods of the post-rebate summer.
- In hot weather conditions, study participants have lower average usage during the daytime hours and higher average usage during the evening and overnight hours.
- In mild weather conditions, study and future participants have similar average usage during overnight and daytime hours. Deviations exist during evening hours, when study participants have higher usage. This could indicate changes in baseline usage for study participants that are unrelated to the rebated thermostat, a form of selection bias.



Mild vs Hot Weather Load Shape Comparison (2/2)

- The previous slide showed 2 example load shapes, but the same patterns were exhibited in several other hot and mild weeks of our study period.
- The evening hour differences on mild days (which may be indicative of selection bias) tend to be between 0.1 and 0.6 kW. Summing these across the 7 evening hours is a difference of 0.24 kWh per account per day.
  - This magnitude is approximately double the selection bias adjustment shown previously.
  - Guidehouse feels the regression-based adjustment is more accurate than the simple difference, since the regression controls for additional variables.

Appendix: ENERGY STAR Analysis Methodology

Guidehouse

Adjustments to the ENERGY STAR METHOD

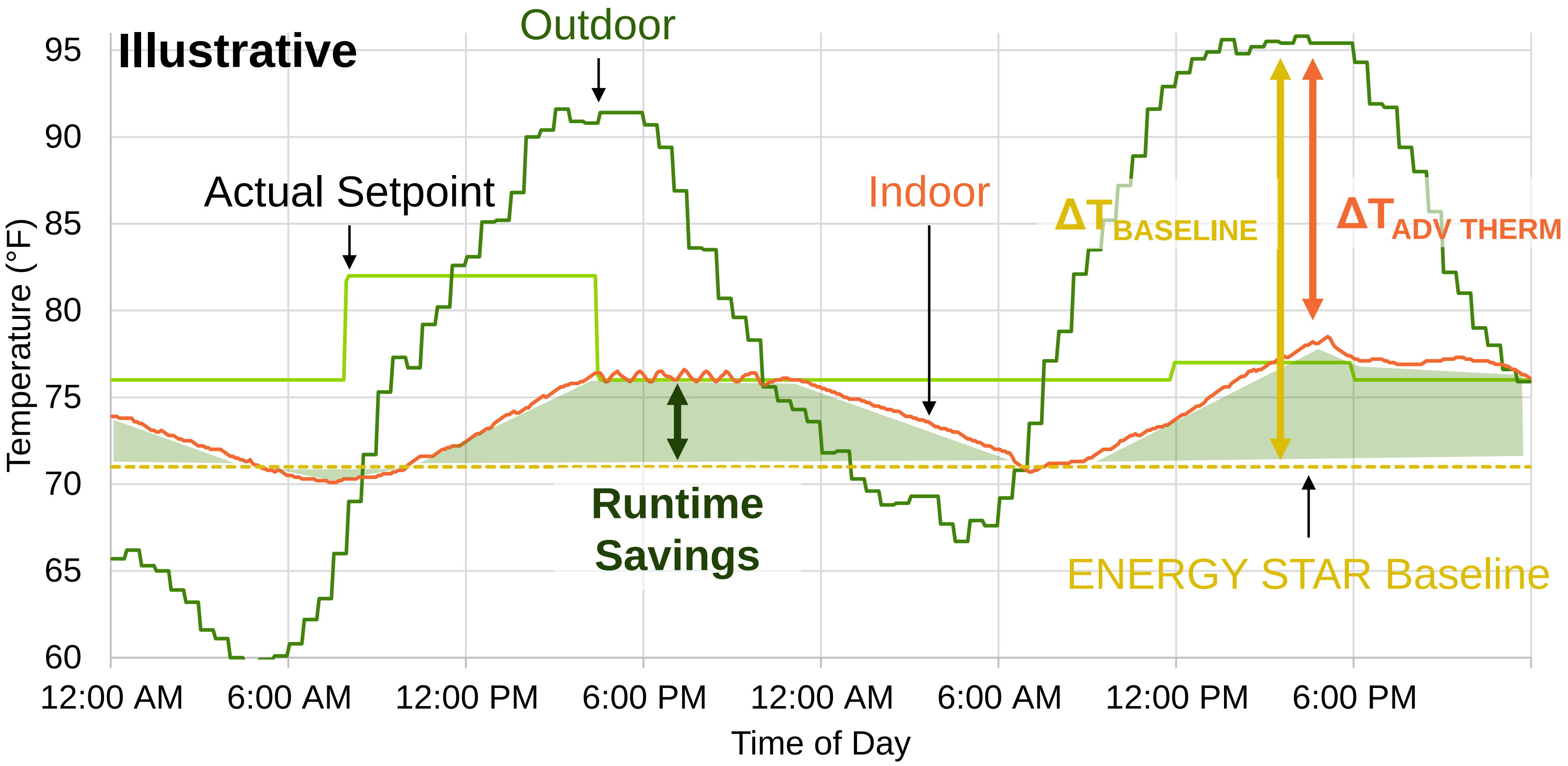
Adjustments address two key questions associated with the current ENERGY STAR method.

- **Baseline comfort temperature**
  - Defined as the 10th percentile (for cooling) and 90th percentile (for heating) of indoor temperature history based on core heating and cooling days
  - How accurate is this approach to identify the true baseline comfort temperature for each customer?

- **Setback behavior**
  - The method assumes a constant baseline temperature in absence of an advanced thermostat
  - To what extent are customers using a programmed setback schedule or a more efficient constant temperature prior to installation of an advanced thermostat?

Illustrative Example

Cooling runtime is related to the average daily difference between outdoor and indoor temperature.



- In this illustrative example, runtime savings are calculated based on the actual observed indoor and outdoor temperatures as recorded by the advanced thermostat, and the assumed ENERGY STAR baseline.
  - $\Delta T_{ADV\ THERM}$ (in orange): The difference between actual outdoor and indoor temperatures, i.e., the thermal demand met by the HVAC system after installation of the advanced thermostat.
  - $\Delta T_{BASELINE}$ (in yellow): The difference between actual outdoor and baseline indoor temperatures, i.e., ***the thermal demand that would have been met by the HVAC system in absence of the advanced thermostat.***
- The ENERGY STAR baseline is selected as the 10th percentile of indoor temperature history recorded by the advanced thermostat (i.e., not using actual setpoints).

Appendix: ENERGY STAR Methodology – Baseline Comfort Temperature

Guidehouse

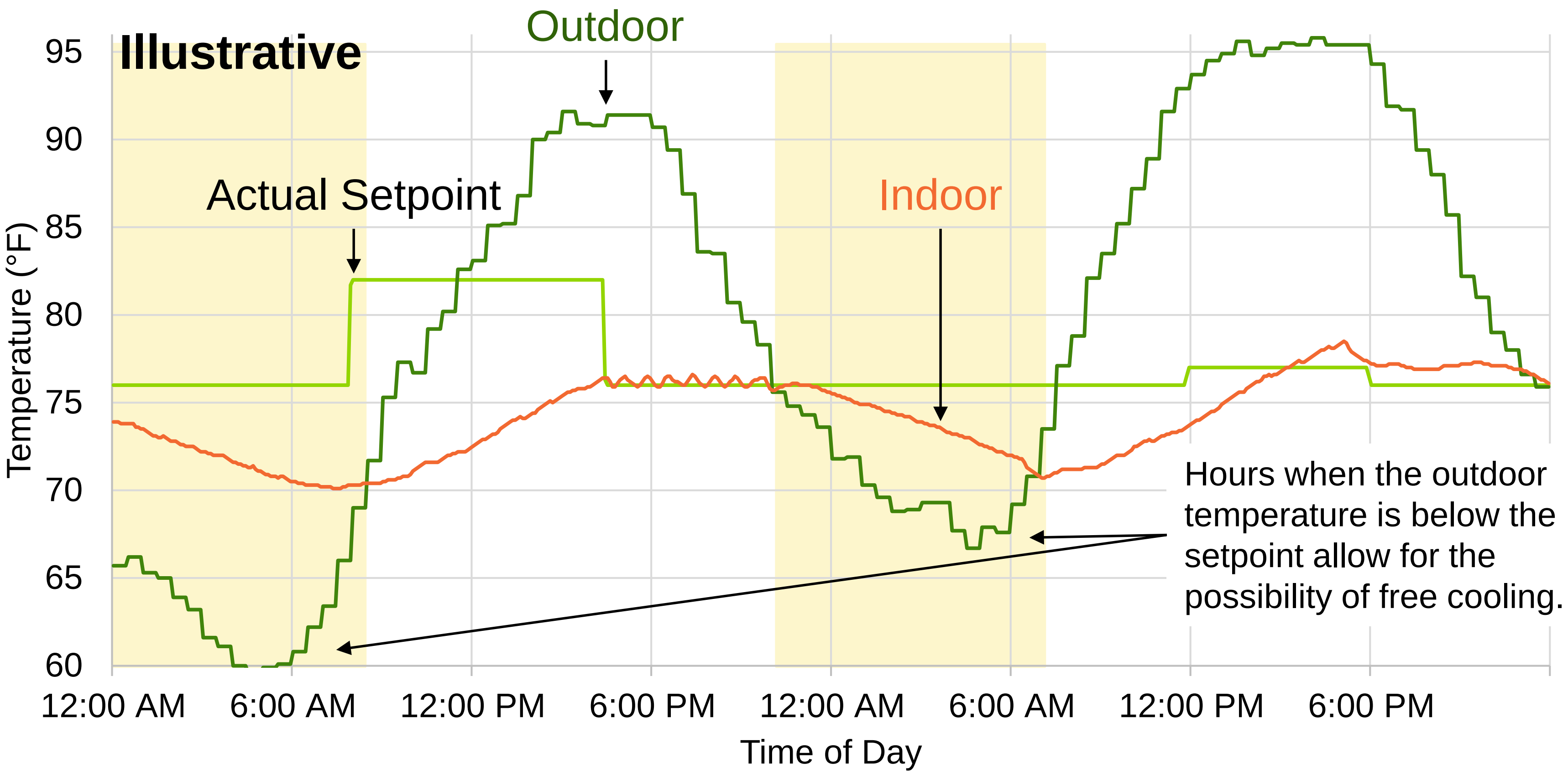
Baseline comfort temperature

Issue: Baseline comfort temperature may be biased high in winter and low in summer because the method does not consider free cooling and heating.

- Baseline comfort temperature may appear too low on days when the outdoor temperature gets below the setpoint (free cooling)
  - The definition of core cooling days includes days where the low temperature gets into the 60s (cooler than typical setpoints)
- Baseline comfort temperature may appear too high in the afternoon on mild days due to solar gains (free heating)
  - The definition of core heating days includes days where the space temperature rises above the setpoint during the afternoon because of free solar heating

Free Cooling Example

The definition of core cooling days may include days where the low temperature gets into the 60s, allowing for free cooling.



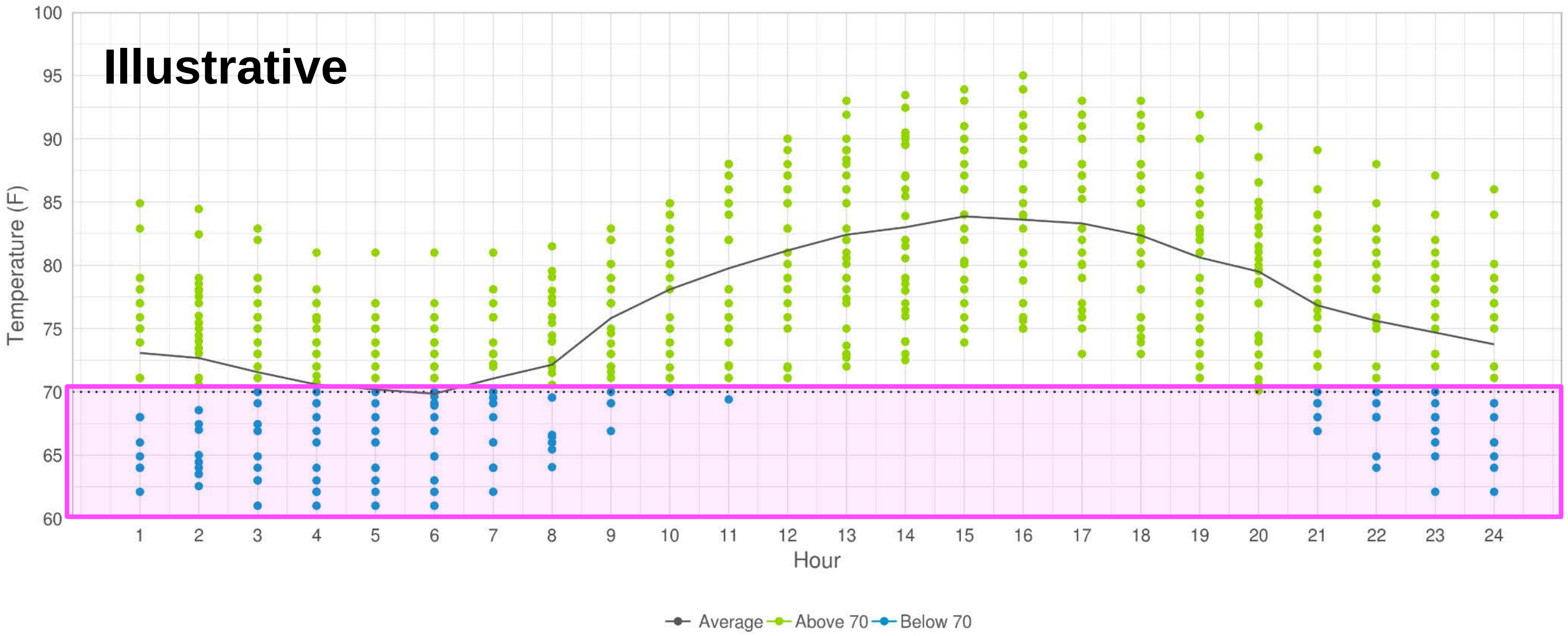
- The definition of core cooling days may include days where the low temperature gets into the 60s, allowing for free cooling.
- During periods of free cooling, indoor temperature may drop below where a person would normally set their thermostat.
- Recorded indoor temperature during these times would be included in the ENERGY STAR baseline selection, which may lead to selecting a baseline temperature lower than a customers true preferred temperature.

Free Cooling Example – Chicago O'Hare

On some days in July (i.e., core cooling days), temperatures drop below 70°F overnight, which allows for free cooling.

Hourly Temperatures in July 2019 – Chicago O'Hare Airport

Each data point represents the temperature of one hour on a day in July 2019

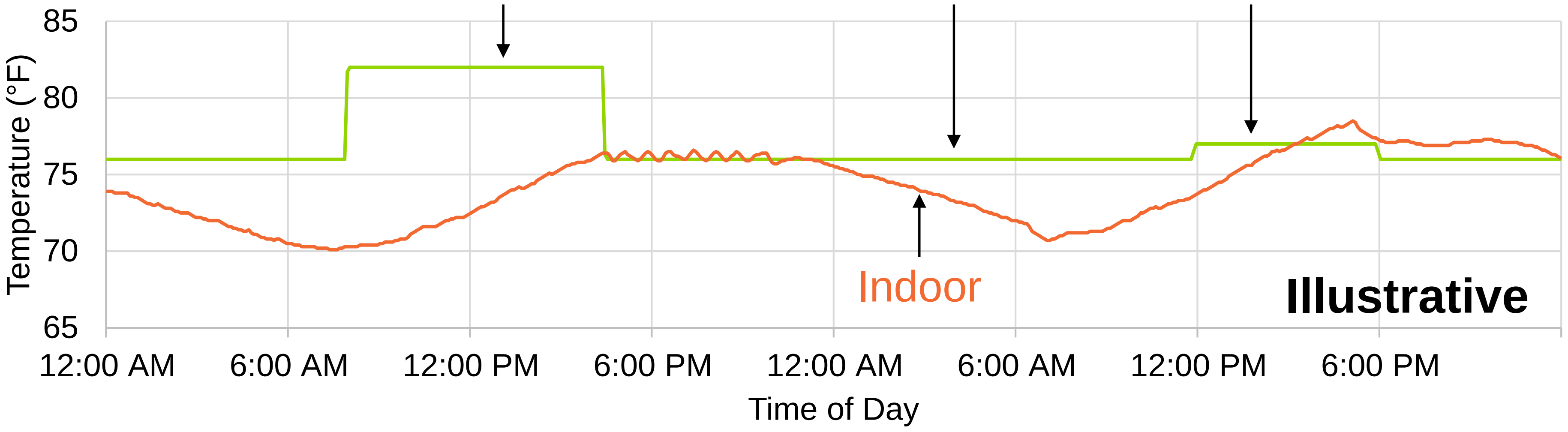


Adjusting the Baseline Comfort Temperature

The setpoint can be used to inform selection of a person’s preferred comfort temperature.

- Could you use only setpoints? This is open to potential biases from people using their thermostat like a switch (e.g., they set a very low temperature to “turn on” cooling, or a very high temperature to "turn off" cooling)
- The key problem is how to select the “true” preferred temperature from the distribution of setpoints.

What setpoints best reflect a person’s desired temperature?



Adjusting the Baseline Comfort Temperature

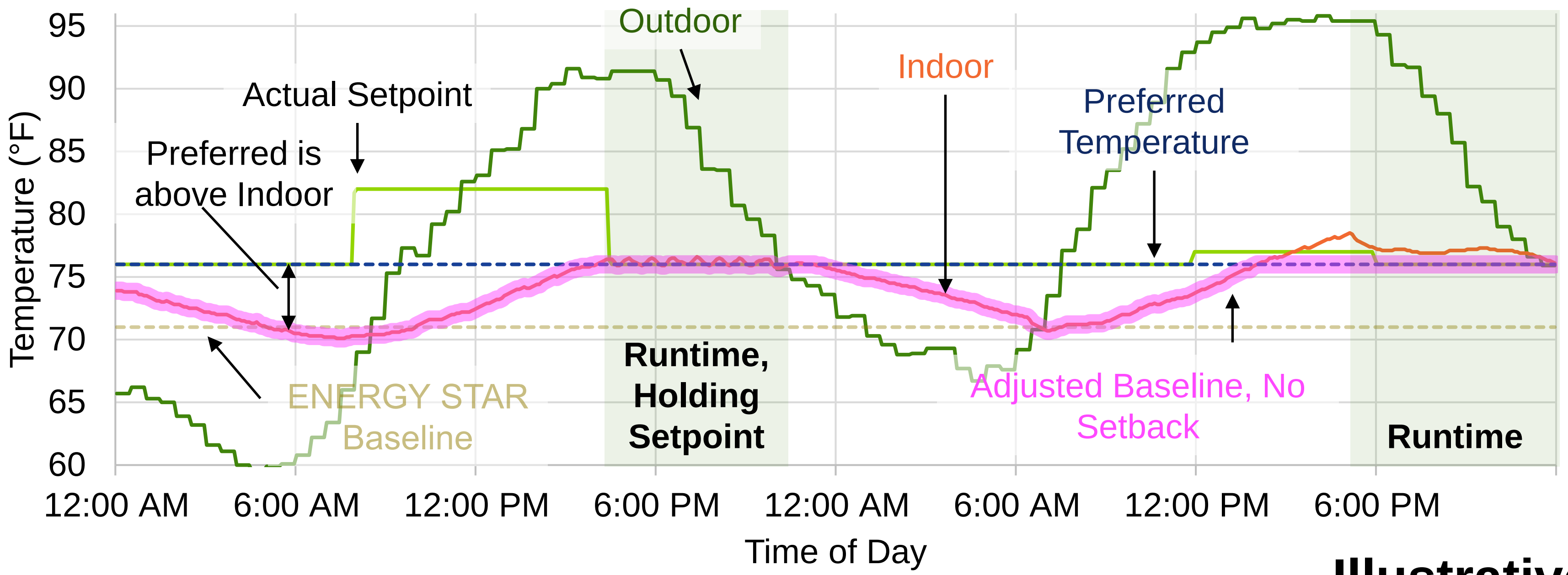
Guidehouse used a method of selecting the preferred comfort temperature method to account for temperature, setpoint, and runtime.

- Rather than including all core cooling day hours:
  - Only include hours with runtime (reduce free cooling or free heating)
  - Only include hours where temperature is within 1 degree of setpoint (i.e., approximately steady state)
- Select the preferred comfort temperature from these hours based on the 10th percentile of temperature for cooling

Adjusting the Baseline Comfort Temperature

Guidehouse used a method of selecting the preferred comfort temperature method to account for temperature, setpoint, and runtime.

- Rather than including all core cooling day hours:
  - Only include hours with runtime (reduce free cooling or free heating)
  - Only include hours where temperature is within 1 degree of setpoint (i.e., approximately steady state)
- Select the preferred comfort temperature from these hours based on the 10th percentile of temperature for cooling.
- At some times, the preferred comfort temperature is above the actual observed indoor temperature (*e.g.*, periods of free cooling). In the adjusted method, the true baseline temperature would follow the actual observed indoor temperature during these periods; i.e., the adjusted baseline is the minimum of the actual indoor temperature and the preferred comfort temperature to avoid unrealistic "negative savings."



Illustrative

Appendix: ENERGY STAR Methodology – Set Back Behavior

Guidehouse

Setback behavior

Issue: Customers may be using a programmed or manual setback schedule prior to installation of an advanced thermostat.

- ENERGY STAR method assumes all customers used a constant baseline setpoint temperature during the pre-period
- The evaluators identified three options to adjust for setback behavior in the ENERGY STAR method and followed Option A

Option	Description	Used
A: Adjust ENERGY STAR Algorithm Directly	Edit algorithm to estimate non-constant baseline comfort temperature	✓
B: Measure Temperature and Runtime	Run ENERGY STAR algorithm using measured baseline temperature and runtime	✗
C: Generate Simulated Baseline Data	Run ENERGY STAR algorithm using simulated baseline temperature and runtime	✗

Adjusting for Setback Behavior

Adjust ENERGY STAR Algorithm Directly

1. Derive assumed baseline setback behavior from available data:
   – Previous Guidehouse and Opinion Dynamics survey results

2. Edit ENERGY STAR algorithm to calculate ***adjusted*** baseline runtime using:
   – Sample of device level thermostat telemetry data
   – Baseline setback behavior (i.e., adjusted baseline temperature profile that is not constant)
   – Runtime to thermal demand relationship as determined by the ENERGY STAR algorithm

3. Estimate savings by running the modified ENERGY STAR algorithm to calculate the difference between the adjusted baseline and actual runtimes

Guidehouse

Appendix: ENERGY STAR Methodology – Setpoint Behavior

Guidehouse

Definition of “Setback”

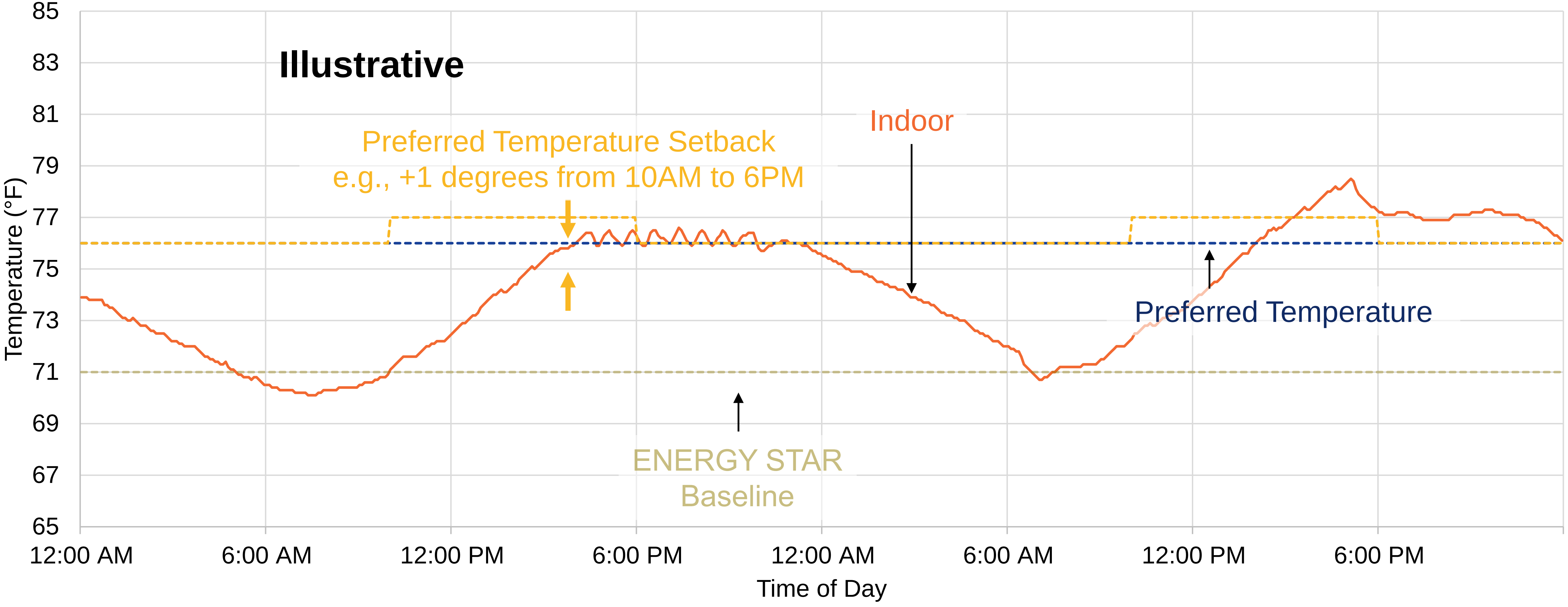
The definition of “setback” behavior may be understood differently by various stakeholders.

- Some stakeholders expressed an understanding of the term “setback” defined as:
  – Indoor temperature minus baseline comfort temperature (for cooling)

- In the current analysis, the evaluators referred to a “preferred temperature setback” as an adjustment relative to the preferred comfort temperature setpoint during certain hours
  – For example, an individual may increase their thermostat setpoint by +1°F from 10 AM to 5 PM

“Preferred Temperature Setback”

The definition of “setback” behavior in the proposed analysis is a change in customer’s preferred comfort temperature.



Guidehouse

Survey Data

Guidehouse and Opinion Dynamics conducted surveys that included questions related to setpoint behavior.

ComEd Participant Survey Data (1,505 Responses) – Guidehouse [available here].

- Guidehouse performed a participant survey in 2018 for ComEd customers who received a rebate for an advanced thermostat between April 2016 through December 2017
- Survey asked about reported setpoints during various times of the day
- Participants report out on their ***current*** setpoint behavior and must recall ***past*** setpoint behavior

General Population Survey (418 ComEd Responses) – Opinion Dynamics [available here]

- Opinion Dynamics performed a general population survey in 2019 of ComEd and Ameren Illinois residential customers
- Includes customers with manual, programmable, and advanced thermostats currently installed in Illinois
- Participants with different types of thermostats report on their setpoint behavior ***during the last cooling season***, similar to the ComEd participant survey

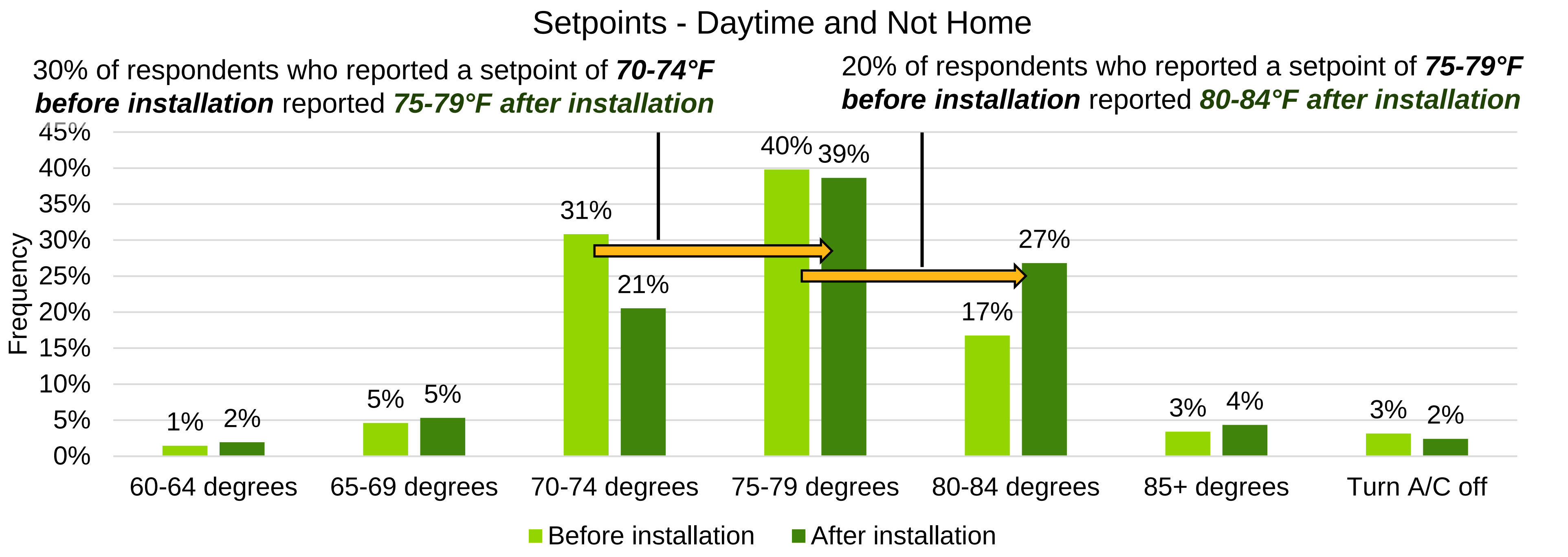
Times of Day

During the day when people are home and awake	During the day when no one is home
During the evening when people are home and awake	During the night when people are asleep

Setpoint Behavior – Participant Survey

ComEd participant survey results include distribution of setpoint ranges during different times of the day before and after installation of an advanced thermostat.

- Setpoints during the *daytime when people are not home* show an increase after installation
- The distributions of reported setpoints during other times of day do not show similar differences before and after installation



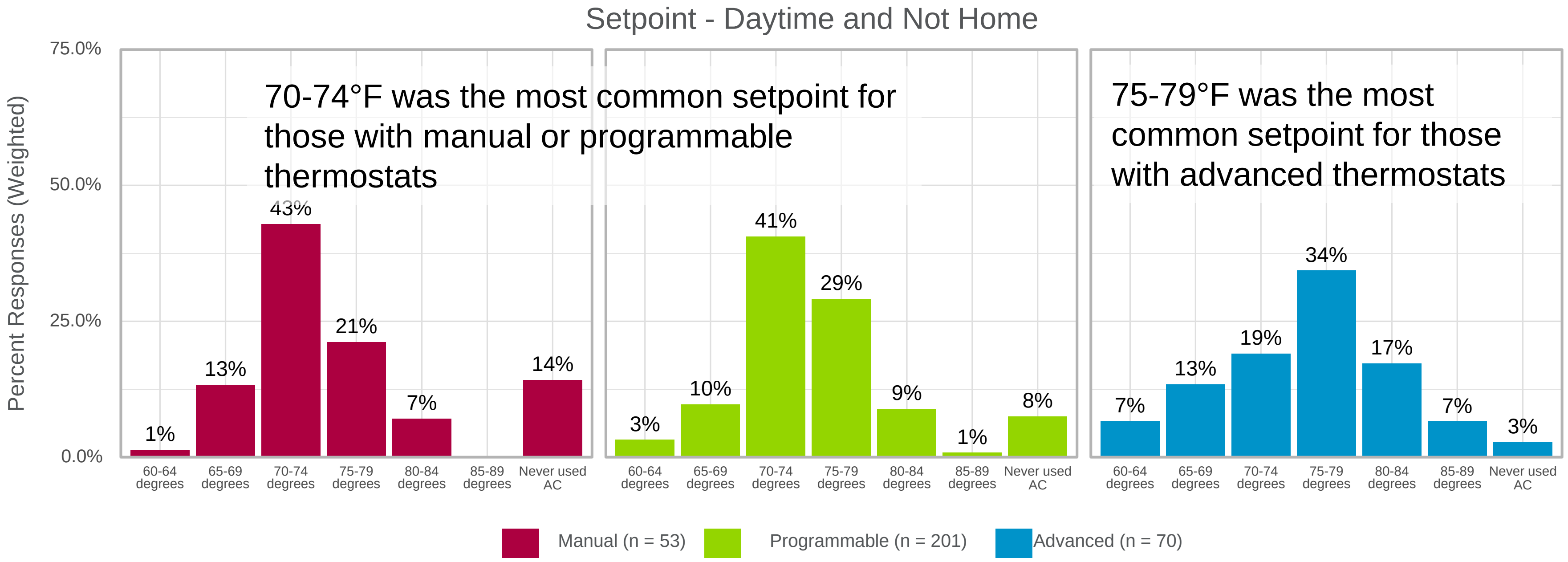
P5.1. Prior to installing the new thermostat, what temperature did you set the thermostat to most often during the summer during the day when no one is home? (n = 412)
P7.1. Since installing the new thermostat, what temperature do you prefer the thermostat adjust to during the summer during the day when no one is home? (n = 414)

Guidehouse

Setpoint Behavior – General Population Survey

General population survey results include distribution of setpoint ranges during different times of the day for different types of thermostats.

- Setpoints during the *daytime when people are not home* show an increase for customers with an advanced thermostat as compared to a manual or programmable thermostat
- The distribution of reported setpoints during other times of day does not show similar differences across thermostat types



ODC Survey - P15a. What temperature did you set your thermostat to most often during the day when no one is home?

Simulated Setpoint Profile

To infer typical setback behavior, Guidehouse developed a simulated daily temperature profile from survey responses.

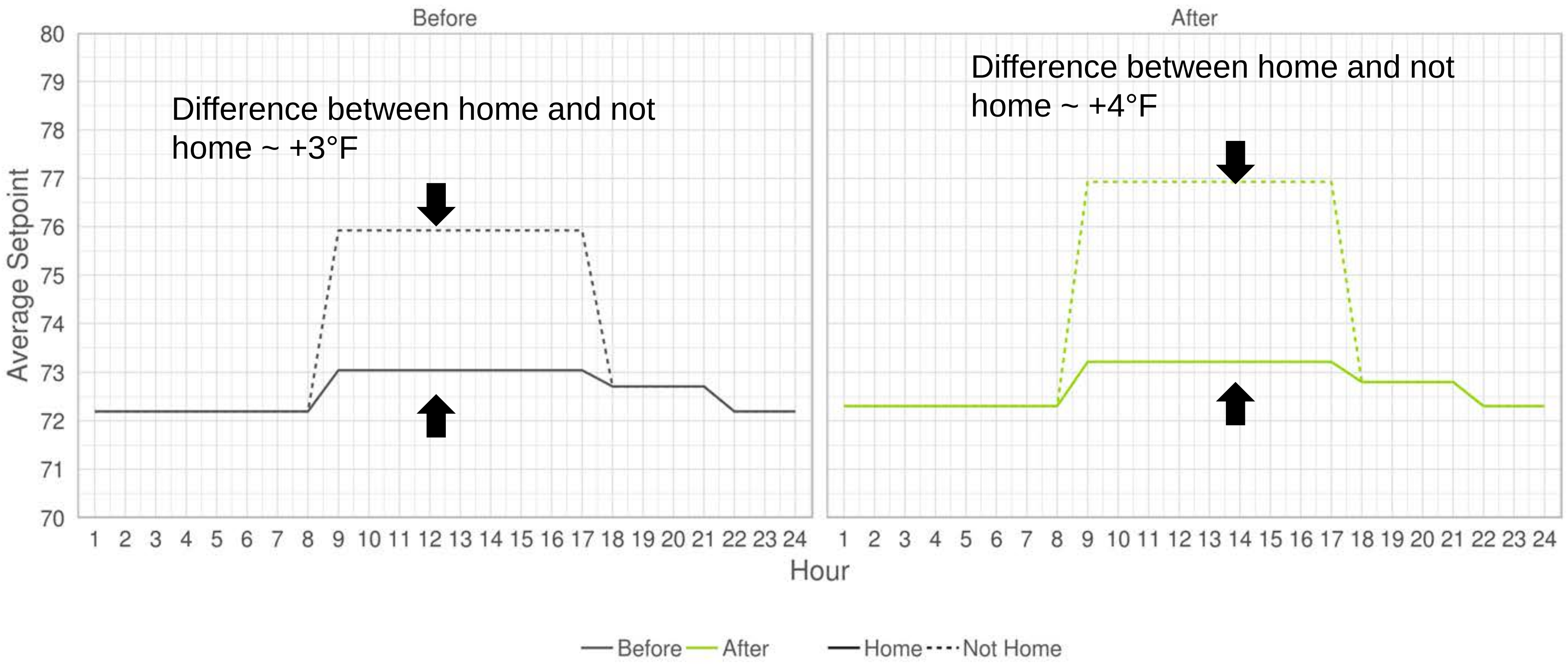
The following steps were taken for responses with / without an advanced thermostat (participant survey) and for each thermostat type (general population survey):

1. For each time of day, assign an approximate time range
2. For each respondent and time of day, assign the midpoint of reported temperature range (e.g., 70-74°F becomes 72°F)
3. Calculate a weighted average setpoint in each time of day based on distribution of responses
4. Use profile to infer how customers use their thermostat during different times and scenarios (e.g. at home vs not at home during the day)

Time of Day	Approximate Time Range
During the day when people are home and awake	8 AM – 5 PM
During the day when no one is home	8 AM – 5 PM
During the evening when people are home and awake	5 PM – 9 PM
During the night when people are asleep	9 PM – 8 AM (Next Day)

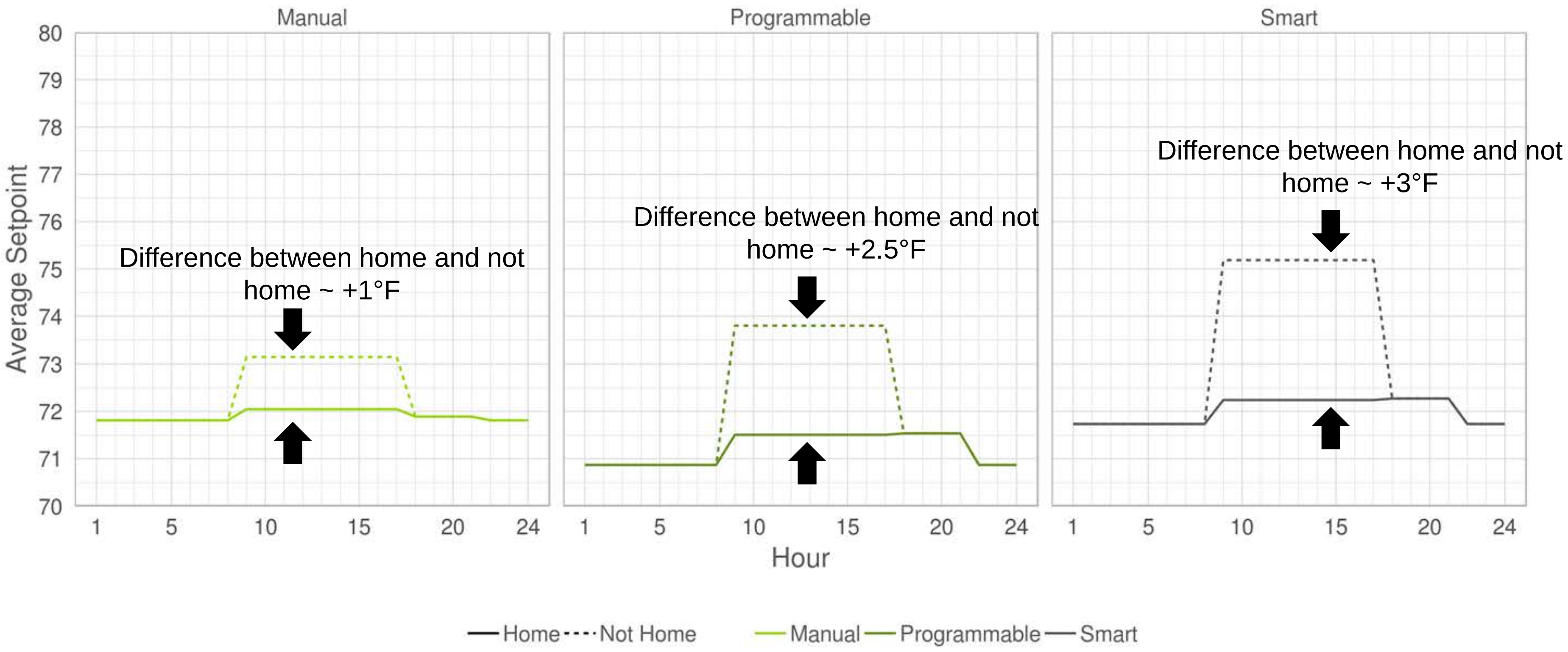
Simulated Setpoint Profile – ComEd Participant Survey

Prior to installation, the average reported setpoint is 3°F higher during the day when participants are home vs not home. The reported difference increases after installation.



Simulated Setpoint Profile – Gen Pop Survey

For manual and programmable thermostats, the average reported setpoint is 1°F and 2.5°F higher when customers are home vs not home, respectively. The reported difference increases for advanced thermostats.



Simulated Setpoint Profile – Caveats

Self-reported data on preferred temperatures does not include some key inputs to fully characterize behavior.

- Share of time the air conditioning system is turned off/not used, such as:
  - Long absences
  - Vacations
  - Turning system off during the day when away
- Share of time when individuals may override programmed thermostat settings
- Share of time when individuals are programming a setback into their thermostat
  - (e.g., only on weekdays, from 8 AM to 5 PM)
- Share of homes to which the “typical” setback behaviors apply (e.g., proportion of people who use a setback when leaving home during the day vs people who stay at home the entire day)

Summary of Setback Parameters

Test a range of setpoint changes relative to the preferred comfort temperature during the day.

- Estimate a range of runtime savings from the adjusted ENERGY STAR algorithm (and compare with standard ENERGY STAR rating) with the following parameters:
  - A range of baseline setpoint changes from ***0 to +4°F*** for the period during the day when no one is home (e.g., ***8 AM to 5 PM***)
  - ***Do not apply a setback for other times of the day*** (i.e., during the evening when people are home and overnight)
  - Daytime setback is applied for ***weekdays only***
  - The evaluators will explore available data to determine ***what percentage of homes should be expected to use this typical setback***
- Estimate sensitivity to changes of the preferred comfort temperature (**+/- 3°F**)
  - Provide context around the magnitude of customers using more or less efficient setpoints (e.g., one issue related to underestimation of savings)

Appendix:
In-Service Rate

Guidehouse

Background

IL TRM v8 Values

From IL TRM v8:

Assumed Annual Energy Consumption

Derive Percentage Cooling Energy Savings

Energy Savings, from econometric analysis

$$\Delta kWh_{cool} = \%AC \times \frac{FLH \times Capacity}{SEER \times 1000} \times Cooling\_Reduction \times Eff\_ISR$$

Effective In-Service Rate

% of Customers with Thermostat-Controlled AC

- The IL TRM v8 uses an ***effective*** in-service rate of 100%; the savings value for “Other” is assumed to be ***derived from an econometric analysis that inherently accounts for devices that are not installed***.

Program Delivery	Effective ISR
Direct Install	100%
Other	100%

- Stakeholders expressed a desire to have the cooling reduction factor reflect the savings of the device as installed, rather than account for devices not installed.

Guidehouse

Background

Definitions

- We will discuss in-service rate in terms of separate installation and leakage rates:
  - ***Installation Rate***: Percent of rebated devices that are installed and active (regardless of where)
  - ***Leakage Rate***: Percent of rebated devices that are installed outside of a utility's (e.g., ComEd's) territory

In-Service Rate [%] = ***Installation Rate*** – ***Leakage Rate***

- The combined ***in-service rate*** represents the percent of rebated devices that are installed and in use in a utility's (e.g., ComEd's) territory.

Guidehouse

Background

Thermostat Installation Channels

- Advanced thermostats are rebated through a number of ComEd energy efficiency programs, which may lead to different in-service rates.
- Guidehouse recommends an ISR of 100% for direct install programs, consistent with the IL TRM v8.
- Guidehouse recommends developing an alternate ISR for self-install channels.

Program	Percent of Thermostats	Installation Channel
Appliance Rebates	93.5%	Customer Self-Install
Residential HVAC	4.2%	Direct Install
Home Energy Assessment	2.2%	Direct Install
Single-Family Illinois Home Weather Assistance	0.1%	Direct Install
Multifamily	<0.1%	Direct Install

Background

Data Availability

Guidehouse had the following data available to estimate installation and leakage rates:

- ComEd and Ameren IL participant survey responses
- Google-provided data on activation of devices*

** ecobee was able to provide a similar set of statistics for participants with ecobee devices. However, 65% of serial numbers reported in ComEd tracking data were not valid ecobee serial numbers; specifically, many serial numbers were truncated, with the last several digits replaced by zeroes. As a result, Guidehouse used the available data as a robustness check and verified similar percentages as determined from Google's data; however, we did not update these numbers due to the large amount of invalid or misreported serial numbers for ecobee devices.*

Appendix:
In-Service Rate – Survey Results

Participant Survey Results

Reported Installation Rates are 97% – 100%

ComEd Participant Survey

- Guidehouse performed a participant survey in 2018 for ComEd customers who received a rebate for an advanced thermostat between April 2016 and December 2017.
- Nearly 100% of customers reported installing their thermostat within a month of purchase (99.7%).

Ameren IL Participant Survey

- Opinion Dynamics performed a participant survey in early 2019 with 1,493 customers who received a rebate for an advanced thermostat in 2018.
- The survey verified thermostat purchase, installation, and persistence.
- 97.4% of all program discounted thermostats were reported as installed and operating at the time of the survey.

Estimates from surveys are likely to have a response bias – customers may be more likely to respond to the survey if they have installed their thermostat than if they have not.

Appendix:
In-Service Rate – Google Activation Data

Guidehouse

Participating Google Devices

Data Available

Guidehouse also used data provided by Google to infer installation and leakage rates for thermostat rebate participants.

Guidehouse provided Google with the following sets of participant device identifiers:

- **Econometric Analysis Group:** Participants who received a rebate for an advanced thermostat on or after Oct 1, 2017 and on or before March 30, 2018), who are also HER participants
  - Thermostats may or may not be installed and in use
- **ENERGY STAR Analysis Group**: Participants who received a rebate for an advanced thermostat after cooling season 2017 (on or after Oct 1, 2017) and before cooling season 2018 (on or before May 31, 2018)
  - Thermostats may or may not be installed and in use
- **Survey Respondents**: participants who responded to the 2018 participant survey and reported installing their rebated advanced thermostat
  - Thermostats most likely to be installed and in use

Google was able to provide the following statistics for each group of participants:

- # of erroneous serial numbers (e.g., wrong length, duplicates)
- # of devices found in Google database (i.e., installed and registered online)
- # of devices activated in Illinois
- # of devices activated outside of Illinois (e.g., in Wisconsin, Indiana, Michigan, Florida)
- # of devices with connected AC

Participating Google Devices

Data Summary

- ComEd participant survey responses suggest that 100% of customers install and currently use their advanced thermostat; only 93.1% of those customers appear in Google's database.
  - This could indicate, for example, typos or misreported serial numbers in program tracking data, or devices that were installed but never activated with Google.
- Some devices (~2.6%) were of incorrect format or length. These serial numbers were excluded from the analysis (assumed to follow the same trends as correct format serial numbers).

Description	Econometric Analysis Group (Percent of Total)	ENERGY STAR Analysis Group (Percent of Total)	Survey Respondents (Percent of Total)
Total Devices (excluding incorrect serial numbers)	10,232 (100%)	20,227 (100%)	1,086 (100%)
Found in Google Database	9,145 (89.4%)	18,412 (91.0%)	1,012 (93.1%)
Matched to Devices in Illinois	8,454 (82.6%)	17,106 (84.5%)	942 (86.7%)
Matched to Devices outside of Illinois	691 (6.75%)	1,306 (6.5%)	70 (6.4%)

Participating Google Devices
Installation Rate

- Google's data for the analysis group implies an installation rate of 89-91%.
  - Caveats:
    - Typos or incorrect entering of serial number in program tracking data may lead to a thermostat not matching to Google's database.
    - Customers may still install and use their device without activating their smart thermostat via the internet.
- Due to these uncertainties, this result may be considered a lower bound (i.e., lowest estimate) of installation rate.

	Description	Econometric Analysis Group	ENERGY STAR Analysis Group
A	Total Devices	10,232	20,227
B	Total Devices Found in Google Database	9,145	18,412
C	**Installation Rate = B / A**	**89.4%**	**91.0%**

Guidehouse

Participating Google Devices

Leakage Rate

- Google's data for the analysis group implies a leakage rate of 6-7%.
  - Caveats:
    - Typos or incorrect entering of serial number in program tracking data may lead to a thermostat matching to an incorrect location (or vice versa).
    - Customers may intentionally or accidentally enter an incorrect ZIP code.
- Due to these uncertainties in location, this result may be considered an upper bound (i.e., highest estimate) of leakage rate.

	Description	Econometric Analysis Group	ENERGY STAR Analysis Group	Survey Respondents*
A	Total Devices	10,232	20,227	1,086
B	Thermostats found in Google database	9,145	18,412	1,012
C	Thermostats matched in Illinois	8,454	17,106	942
D	Thermostats matched outside of Illinois	691	1,306	70
E	**Leakage Rate = C / A**	**6.8%**	**6.5%**	**6.4%**

** The ComEd participant survey asked customers to report whether they installed their thermostat, but not where; customers may have reported installing even if they did so outside of Illinois.*

Appendix:
In-Service Rate – Summary

Guidehouse

Summary

In-Service Rate

- Installation rate
  - ComEd and Ameren IL participant surveys – 97-100%
  - Google device activation data – 89-91% (assumed to be lower bound, due to potential typos)
- Leakage rate
  - Google data – 6-7% (upper bound estimate)
    - Some of these devices may have been actually activated in Illinois but match with devices out of state due to typos in serial number (program tracking data), or incorrect / misreported ZIP codes.
  - We assume the lower bound on the leakage rate is 0% (all are typos or incorrect ZIP codes).
- Through discussions, VEIC (IL TRM Administrator) recommended an ISR of 90%, reflecting the leakage rate 6-7% and an assumed percentage of devices that are never installed (3-4%)

Program Delivery	ISR
Direct Install	100%
Customer Install (e.g. Leave Behind) / Other	90%