Guidehouse
Outwit Complexity

EM&V Report for the EnergyWise Home Demand Response Program

Prepared for:

DUKE ENERGY®

Duke Energy Progress EnergyWise Home

FINAL

February 1, 2023

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Executive Summary

The EnergyWise Home (EWH) demand response (DR) program offers Duke Energy Progress (DEP) residential customers the opportunity to earn credits on their electricity bill by allowing DEP to remotely cycle and curtail air conditioners (A/C) during times of peak seasonal load in the summer months (available system wide) and space- and water-heating equipment in winter months (available for western region customers only).

This report covers the evaluation, measurement, and verification (EM&V) activities for the winter of 2021/2022. For this evaluation, Guidehouse evaluated EWH program impacts using whole-home quarter-hourly interval data provided by DEP's Advanced Metering Infrastructure (AMI), as well as appliance-level logger data for select customers.[1]

The evaluation conducted for the winter of 2021/2022 is similar to the EWH evaluation conducted for the summer of 2018/2019, where estimated impacts using both AMI and logger data were compared side-by-side. An important distinction between this year's evaluation and that of the 2018/2019 summer period was the addition of on-site verification visits by a third-party contractor (Franklin Energy), designed to verify the working order of devices and equipment. Data from verification visits were used to further parse the impact and efficacy of the EWH demand response program.

Duke will remove customers from the EWH program if they refuse a verification visit, as Duke cannot verify the working order of those devices. As such, final ex-ante and ex-post program impacts are provided only for those sites that received an on-site verification visit. This is a marked deviation from prior evaluations, as roughly one tenth of the entire EWH population received a verification visit. As a result, reported impacts this year are an order of magnitude smaller than those of the 2020/2021 winter evaluation.

At the start of the winter 2021/2022 DR season, the EWH program had 12,936 participants eligible for winter curtailment in DEP's western region, representing approximately 11,208 controlled water heaters and 6,340 controlled heat pump auxiliary heat strips. DEP called 24 water heater and 15 heat strip EM&V events that applied only to a sample of nearly 10,000 EM&V sample participants. Of these 10,000 EM&V sample participants, 1,017 received a verification visit. In addition, there were five program-wide events called in the winter of 2021/2022, which applied to all participants enrolled in the program.[2]

Table ES-1, below presents a summary of average ex-ante and ex-post program impacts.

- **Ex-ante impacts** represent the projected program capability at design conditions: 10°F for heat strips, and between 7:30am and 8:30am Eastern prevailing time for water heaters.
- **Ex-post impacts** represent the estimated impact (per participant and per appliance) across all hours of population events called during the winter of 2021/2022.

[1] Customers that received loggers were those participants that received a verification visit from Franklin Energy and that had consented to additional data collection via logger devices.

[2] Program-wide events are events that are called by Duke Energy to curtail the load of all enrolled customers in the EWH program. Events that are not program-wide events (i.e., EM&V events) are only called for participants that are in the EM&V subsample of the EWH participants.

In the ex-ante capability rows of the table below, the “Total Program Impact (MW)” is the program capability: the product of the impact per appliance estimated for the EM&V sample and the total population of participants that received a site verification visit.

Table ES-1. Summary of Program Impacts

	Appliance Type	Cycling Strategy	Impact per Participant (kW)	Relative Precision +/-% (90% Confidence)	Impact per Appliance (kW)	Total Program Impact (MW)
Projected Capability (Ex-ante)	Heat Strips	100%	0.57	11%	0.53	0.37
	Water Heaters	100%	0.29	16%	0.29	0.28
EM&V Event Impact – Winter 2021/2022 (Ex-post)	Heat Strips	100%	0.31	13%	0.29	0.20
	Water Heaters	100%	0.28	14%	0.27	0.26
Population Event Impact – Winter 2021/2022 (Ex-post)	Heat Strips	100%	0.34	12%	0.32	0.23
	Water Heaters	100%	0.37	11%	0.36	0.36

Note: The program total impact was estimated by multiplying the average impact per participant by the number of participants that have received a verification visit from Franklin Energy.

Source: Guidehouse analysis

While per-participant impact estimates are greater than the estimates provided in the 2020/2021 report, the estimates are still lower than expected. Based on an investigation of logger data available for a select number of customer sites, the most likely explanation for lower-than-expected estimated impacts is a high level of curtailment failure at the appliance level, particularly among heat strips. Using appliance logger data from a random subset of participant sites that received a verification visit from Franklin Energy, Guidehouse identified that many heat strips did not appear to respond to the signal from Duke Energy to curtail, despite having received a verification visit.

Evaluation Objectives

The key objectives of the impact analysis include:

- **Estimating demand response impacts (kW).** Guidehouse has estimated the average impact of curtailment by equipment type, per participant, for participants that had received the switch verification visit from Franklin Energy, for every quarter-hour of each event to which EM&V participants are subject.
- **Estimating the program-level DR impact per population-wide event.** Based on regression-estimated relationships, observed temperatures, and the findings of the field work and switch responsiveness analysis, Guidehouse has estimated the average demand impact of the program for each event to which the entire program population was subject.

- **Estimating hourly kW snapback impacts.** Guidehouse has estimated the average kW snapback[3] impact for all EM&V events.
- **Estimating average event load shed capability (ex-ante impacts).** Guidehouse has applied the regression-estimated impact parameters to a range of event temperatures to deliver a projected load shed under a variety of weather conditions. As in previous years' evaluations, this is presented graphically in the body of the report. The values underlying this plot are also included in the Appendix D. Demand Response Impacts Spreadsheet spreadsheet that accompanies this report.
- **Providing a clear technical description of the analytic approach.** Although not an output of the analysis itself, Section 2.4 and Appendix A. Regression Model Specification provide a clear explanation of the approach such that the results may be reasonably reproduced by a qualified third party provided with the same data.
- **Comparing logger and AMI-based impacts.** Guidehouse has compared impacts estimated from logger data with impacts estimated from AMI data to investigate one hypothesis articulated in the winter 2020/2021 report;[4] whether the reduction in average savings was a result of the shift from a logger-based evaluation to an AMI-based evaluation in that evaluation year.

Evaluation Methods

Guidehouse's impact evaluation approach includes three components:

- Sample Selection and Experimental Design
- EM&V Regression Estimation
- Comparison of Winter 2021/2022 Impacts with Winter 2020/2021 Impacts

Sample Selection and Experimental Design

The estimated impacts presented in this evaluation report are based on a sample of participants from the overall participant population that were randomly chosen and received verification visits from Franklin Energy. Based on lessons learned in previous evaluations, auxiliary heat strip customers were over-sampled to target improved confidence and precision of the regression.

As in all previous evaluations since 2016, Guidehouse worked with DEP to carefully select EM&V events to maximize the value of information they provided for the estimation of program capability and used a robust experimental design to ensure estimates of impacts are unbiased. In this case the experimental design requires that for any given EM&V event only half of the EM&V sample is curtailed, ensuring a contemporaneous control group for all events.

EM&V Regression Estimation

[3] Snapback refers to the manner in which demand from water heaters or HVAC systems tends to rise considerably above normal levels in the period immediately following a DR event as the equipment works to restore water or air temperature to its set-point level. Snapback impacts are not included in the body of the report, but may be found as tables and figures in Appendix D, the spreadsheet appendix that accompanies this report.

[4] The previous evaluation report for the EnergyWise Home program, covering winter 2020/2021 events, may be found here: **https://starw1.ncuc.gov/NCUC/ViewFile.aspx?Id=c7bcf5fe-8bd5-4f29-9c76-01d5aba52631**

As in previous years, impacts were estimated via use of panel data fixed-effects regression. Additional detail about the regression used in this evaluation can be found in Appendix A. Regression Model Specification.

Comparison of Winter 2021/2022 Impacts with Winter 2020/2021 Impacts

The most significant finding of the winter 2021/2022 evaluation of the EWH program is the continuation of the degree to which estimated impacts are lower than expected. Table ES-2, below, provides the average estimated ex-post impact of water heater impacts from winter 2020/2021 and winter 2021/2022 years. These events started as early as 6am and ended as late as 10am, though the vast majority took place no earlier than 6:30 or no later than 9:00. Impacts estimated for the winter 2021/2022 period are slightly greater than those estimated for the winter 2020/2021 period.

Table ES-2. Comparison of Average Ex-Post Water Heater Impacts from Prior Evaluations

Evaluation Year	Estimated Average Impact Per Water Heater (kW)
2020/2021	0.21
2021/2022	*0.27*

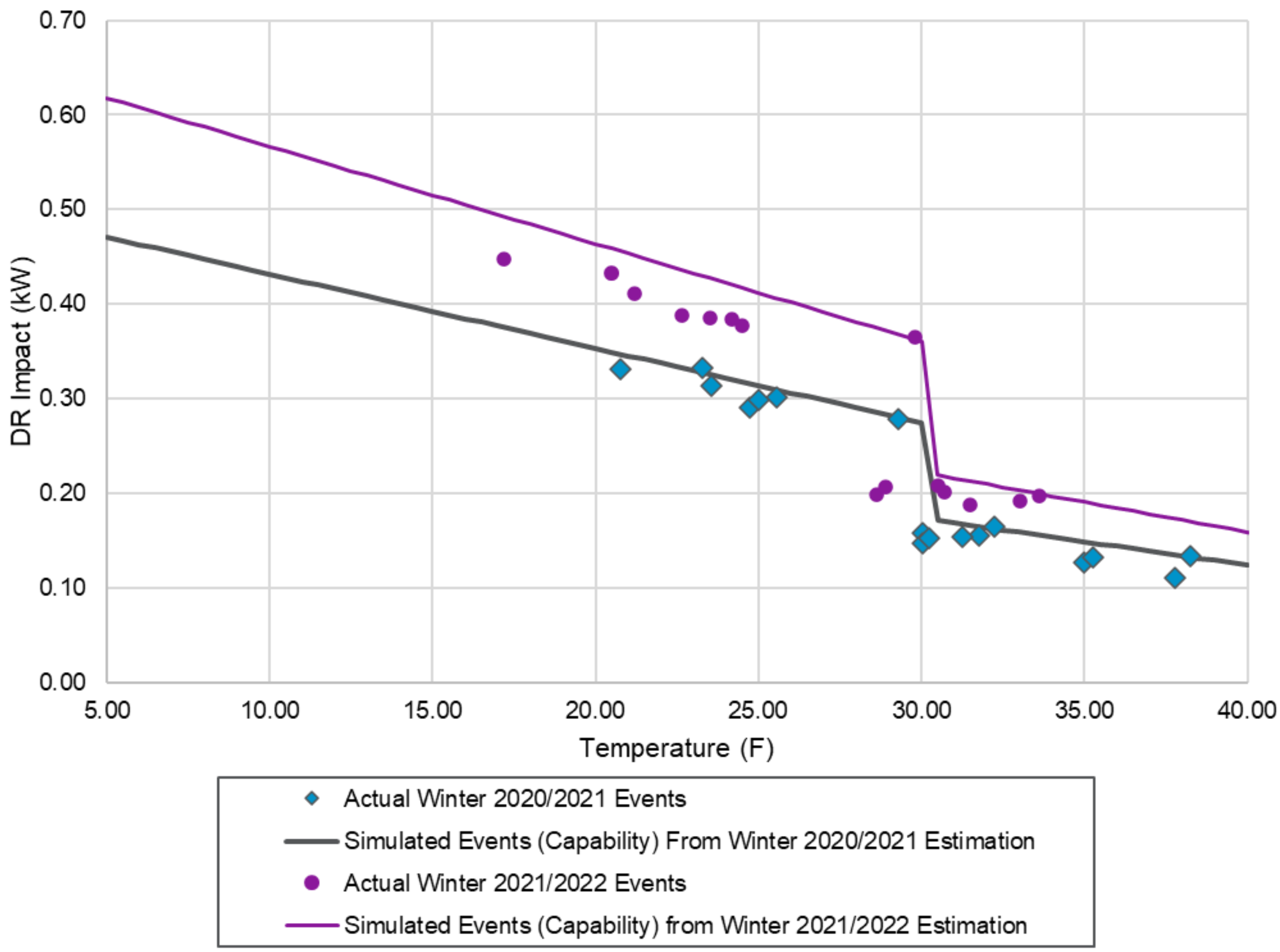
Source: Guidehouse analysis

Heat strip impacts, unlike water heaters, have been much more variable in prior evaluations. This is due to fluctuation in responsiveness and impacts, both of which change with respect to temperature. When temperatures are sufficiently warm, heat strips will not be in use, so responsiveness and impacts tend to be low. Impacts increase as temperature decreases; however, when temperatures are very cold, partial responsiveness increases due to the heat strips' emergency defrost capability overriding curtailment.

A comparison of heat strip capability can be seen Figure ES-1 below. This plot shows the average event impact (kW) per appliance and temperature (Fahrenheit) pairs from the winter 2020/2021 and winter 2021/2022 evaluations.[5] The lines indicate the estimated capability per appliance at a range of different temperatures for each evaluation year. Note the observable change in relationship between temperature and impact between evaluations, with heat strip capability estimates slightly greater when derived from the winter 2021/2022 period as compared to the winter 2020/2021 period.

[5] A table of values that includes all the data points shown in this plot may be found in Appendix D, the spreadsheet appendix that accompanies this report.

Figure ES-1: Comparison of Heat Strip Capability



Note: Winter 2021/2022 capability estimates are presented for participants that received a verification visit from Franklin Energy.

Source: Guidehouse analysis

Findings and Recommendations

The principal EM&V impact findings and conclusions regarding the winter event demand impacts for 2021/2022 are as follows:

- **Average estimated impacts and projected capability are higher than estimated in the winter 2020/2021 evaluation.** During EM&V events, Guidehouse estimated average demand reductions of 0.31 kW per heat strip participant and 0.27 kW per water heater participant. These estimates are 0.10 kW and 0.05 kW higher, respectively, than those of the 2020/2021 evaluation. During population events, Guidehouse estimated average demand reductions of 0.34 kW per heat strip participant and 0.37 kW per water heater participant. Guidehouse's projected capability of savings are 0.57 kW per heat strip and 0.29 kW per water heater. In comparison to the winter 2020/2021 evaluation estimates, projected capability has increased by 0.14 kW per heat strip participant and 0.03 kW per water heater participant.

- **The estimated average impact of the winter 2021/2022 EM&V water heater events was 0.27 kW per participant.** This represents the average of the estimated impacts across 24 water heater events taking place between 7:00 and 9:00 in the morning. This average per participant impact is higher than the 0.21 kW per participant that was estimated in winter 2020/2021
- **The estimated average impact of heat strips over the four coldest events during the winter 2021/2022 season was 0.42 kW per participant and 0.39 kW per appliance.** The average temperature across these events was approximately 20°F, with a minimum observed temperature of 17°F.
- **The current DR capability of DEP's EnergyWise program in the winter is approximately 0.64 MW**. Note that this estimate includes only the households that received a verification visit and is the summation of the projected capability of 0.37 MW from heat strip curtailment when the average temperature is 10°F (0.53 kW per appliance) and 0.28 MW from water heater curtailment deployed between 7:30 and 8:30 in the morning (0.29 kW per appliance).
- **There is no statistically significant difference in impact estimates derived from AMI-based data or logger-based data**. One of the principal motivations for reincorporating logger data into this year's evaluation was to confirm the robustness of evaluating DEP EWH impacts from whole-home AMI data and to rule out the theory that the change from appliance-based logger data to whole-home AMI data was responsible for the decrease in savings estimated between the 2017/2018 and 2020/2021 evaluations. Guidehouse confirmed that whole-home AMI data is a valid source of data in determining the impacts of DR events on appliance-level demand and that the magnitude of estimated impacts is comparable between both data sources.

The principal EM&V recommendations regarding the winter event demand impacts for 2021/2022 are as follows:

- **Continue to use AMI data in future evaluations of the EWH program.** Based on comparisons of logger-based and AMI-based impact estimates, Guidehouse identified no differences in assessed impacts between the two parallel data streams. Guidehouse believes that a switch from logger-based impact reporting to AMI-based reporting is not the cause of the lower-than-expected impacts estimated in this evaluation. Combined with AMI data's ability to capture whole-home load and secondary increases in consumption across other end-uses (e.g., increased use of space heating equipment) and its substantially lower cost compared to logger data, Guidehouse recommends continued use of AMI data in order to inform program impact estimates.
- **Continue to work with Franklin Energy to identify and remediate causes of reduced impacts.** Investigation of appliance logger data collected from a subset of sites that received a verification visit revealed continued non-responsiveness of heat strips, despite these devices having received a verification visit. Guidehouse recommends that Duke Energy continue to work with Franklin Energy to visit sites that previously received a verification visit to inspect equipment functionality.

1. Introduction

The EnergyWise Home (EWH) program provides residential customers the opportunity to earn credits on their electricity bill by allowing Duke Energy Progress (DEP) to remotely cycle air conditioning (in the summer) and curtail water heaters and heat pump auxiliary heat strips (in the winter for Western region customers only) during times of seasonal peak load. This report covers the evaluation, measurement, and verification (EM&V) activities for the winter of 2021/2022. At the start of the winter 2021/2022 DR season, the program had 12,936 participants eligible for winter curtailment in DEP's Western region, representing 11,411 controlled water heaters and 6,766 heat pump auxiliary heat strips.

EM&V refers generally to the assessment and quantification of the energy and peak demand impacts of an energy efficiency or DR program. For DR programs, estimating reductions in peak demand is the primary objective, as energy impacts tend to be negligible.[6] Guidehouse estimated impacts across 24 water heater events and 15 heat strip events using quarter-hourly AMI data for a sample of 1,017 participating households that received a verification visit from Franklin Energy.

In addition to estimating impacts from AMI data for participants that received a verification visit, Guidehouse also estimated impacts from appliance-level logger data for a select group of customers that received loggers.[7] The logger data and AMI data were used in a side-by-side analysis to confirm the robustness of evaluating DEP EWH impacts from whole-home AMI data and to rule out the theory that the change from appliance-based logger data to whole-home AMI data was responsible for the decrease in savings estimated between the 2017/2018 and 2020/2021 evaluations.

1.1 Objectives of the Evaluation

The key objectives for the impact analysis conducted as part of this evaluation were identified in Guidehouse's evaluation plan; these include the following:

- **Estimating demand response impacts (kW).** Guidehouse has estimated the average impact of curtailment by equipment type, per participant, for participants that had received the switch verification visit from Franklin Energy, for every quarter-hour of each event to which EM&V participants are subject.
- **Estimating the program-level DR capability per population-wide event.** Based on regression-estimated relationships, observed temperatures, and the findings of the field work and switch responsiveness analysis, Guidehouse has estimated the average demand impact of the program for each event to which the entire program population was subject.
- **Estimating hourly kW snapback impacts.** Guidehouse has estimated the average kW snapback[8] impact for all EM&V events.

[6] Energy impacts from DR events within any given day are usually relatively low. This is because DR events are designed to shift the timing of energy consumption to other hours of the day, rather than reduce overall energy usage.

[7] Customers that received loggers were those participants that received a verification visit from Franklin Energy and that had consented to additional data collection via logger devices.

[8] Snapback refers to the manner in which demand from water heaters or HVAC systems tends to rise considerably above normal levels in the period immediately following a DR event as the equipment works to restore water or air temperature to its set-point level. Snapback impacts are not included in the body of the report, but may be found as tables and figures in the spreadsheet appendix that accompanies this report.

- **Estimating average event load shed capability (ex-ante impacts).** Guidehouse has applied the regression-estimated impact parameters to a range of event temperatures to deliver a projected load shed under a variety of weather conditions. As in previous years' evaluations, this is presented graphically in the body of the report. The values underlying this plot will are also included in the Appendix D. Demand Response Impacts Spreadsheet that accompanies this report.
- **Providing a clear technical description of the analytic approach.** Although not an output of the analysis itself, Section 2.4 and Appendix A. Regression Model Specification provide a clear explanation of the approach such that the results may be reasonably reproduced by a qualified third party provided with the same data.
- **Comparing logger and AMI-based impacts.** Guidehouse has compared impacts estimated from logger data with impacts estimated from AMI data to investigate the hypothesis articulated in the winter 2020/2021 report; whether the reduction in average savings is a result of the shift from a logger-based evaluation to an AMI-based evaluation in that evaluation year.

1.2 Program Overview

The EWH program was developed in response to DEP's determination that a curtailable load program would be a valuable resource for the company and that it would provide an opportunity to engage directly with customers to help reduce costly seasonal peak demand. The program seeks to attract DR participation by incenting residential customers to allow DEP to remotely control water heater and heat pump auxiliary heating strips in the winter months (e.g., December through March). More detail on program characteristics is provided below.

Program Eligibility. To be eligible for participation in the winter component of the EWH program, a household must meet the following criteria:

- **Auxiliary Heat Strip Participants:** The participant's home must use a centrally ducted heat pump with resistive strip heat for space heating. Wall, window, and ductless units are not eligible for participation. All central heat pump units in the home must be controlled by DEP as part of the EWH program.
- **Water Heater Participants:** The participant's home must use an electric storage water heater for domestic hot water service.
- **All Participants:** Residential electricity service must be in the name of the participant.

Program Incentives. Each participant receives a $25 bill credit upon joining the summer program, then an additional $25 bill credit every 12 months they remain enrolled in the program. Each participant receives a $50 bill credit upon joining the winter program, then an additional $50 bill credit every 12 months they remain enrolled in the program.

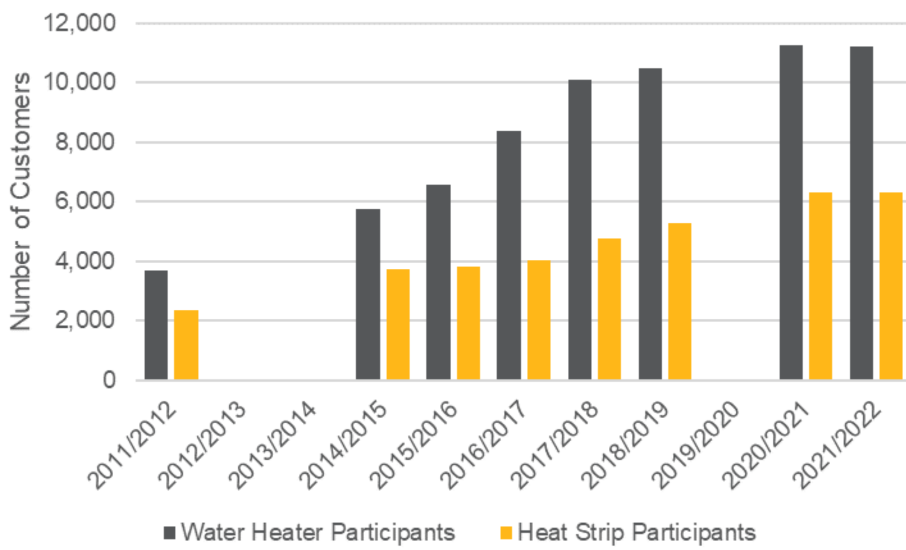
Program Marketing. DEP is responsible for all marketing of the EWH program. Participant enrollments are generated through a mix of direct mail, bill inserts, email, outbound calling, and door-to-door canvassing.

Verification Visits. In response to the relatively low savings estimates estimated during the winter 2020/2021 evaluation, DEP hired Franklin Energy to conduct onsite visits of DR participants and verify the working order of their devices and equipment.

1.3 Reported Program Participation

This section reports the overall program participation for the EWH program in the winter of 2021/2022. In total, at the beginning of the DR season there were 12,936 customers enrolled in EWH and eligible for curtailment. Comprising this group were 11,208 participants with water heaters and 6,340 participants with heat strips. Since the winter of 2011/2012, program growth has been tapering off (see Figure 1-1), although there was a slight decrease in the number of customers participating in the winter 2021/2022 season.

Figure 1-1. Year-to-Year Count of EnergyWise Program Participants[9]



Source: DEP Tracking Data

Altogether, the 11,208 water heater participants that were enrolled at the start of the winter 2021/2022 DR season have a total of 11,411 water heaters enrolled, or approximately 1.02 per participant. The 6,340 heat strip participants that were enrolled at the start of the winter 2021/2022 DR season have a total of 6,766 auxiliary heat strips enrolled, or approximately 1.07 per participant. These ratios have not materially changed over time; the average number of water heaters per water heater participant from the winter of 2015/2016 through the winter of 2017/2018 was 1.02. The average number of heat strips per participant in the same period was 1.08.[10]

1.4 Prior Year Evaluations

Guidehouse's evaluations of the EWH program for prior years are available online and can provide valuable context for the current evaluation. In this evaluation report, Guidehouse provides comparisons between estimates from winter 2021/2022 and estimates from the prior evaluation period (winter 2020/2021). The location of the winter 2020/2021 evaluation report is provided below for the readers' consideration.

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[9] The winters of 2012/2013, 2013/2014, and 2019/2020 were not evaluated so participant numbers are not available. For the winter of 2018/2019 only device counts (rather than participant numbers) were reported. Total participant numbers in this year were calculated by summing the total count of customers in Duke's EWH tracking data after customers who failed readdressing were removed.

[10] Evaluations reported both number of participants and device count by appliance type only in these three years.

Winter 2020/2021 (pdf page 1-84)

https://starw1.ncuc.gov/NCUC/ViewFile.aspx?Id=c7bcf5fe-8bd5-4f29-9c76-01d5aba52631

2. Impact Evaluation Methodology

This chapter of the evaluation report provides a description of the approaches used to conduct the impact evaluation. Additional technical details of the approach used may be found in Appendix A. Regression Model Specification.

Guidehouse estimated demand reduction and snapback impacts using a fixed effects regression analysis applied to quarter-hourly participant interval data drawn from DEP's AMI system, interval data drawn from participants with appliance loggers installed, weather data, and data flags indicating the intervals in which events took place. The remainder of this chapter details the data and the econometric methods used in the analysis.

This chapter is divided into five sections:

- **Data Sources.** This section describes the data employed to estimate the impacts of the winter 2021/2022 curtailment events.
- **EM&V Sample Participants, Events.** This section describes the sample of participants exposed to the EM&V events, and the timing and temperatures associated with those events.
- **Contractor Visits and Switch Verification.** This section describes Duke Energy's efforts to verify the working order of devices controlled by the program during curtailment events.
- **Method for Estimating Capability and Impacts.** This section describes the empirical approach used by Guidehouse to estimate the relationship between event periods and event impacts required to deliver ex-ante (capability) and ex-post (historical) impacts.
- **Method for Estimating Device Responsiveness.** This section summarizes the methods employed by Guidehouse to understand whether devices controlled by the program are responding as expected during curtailment events.

2.1 Data Sources

The impact evaluation made use of five sources of data:

- **AMI data.** Quarter-hourly interval AMI consumption (kWh) data collected from EM&V participants' AMI meters.
- **Logger data**. Five-minute interval logger data from a select group of EM&V participants' appliances. Prior to the winter 2021/2022 season, the evaluation team installed data loggers at a sample of homes in the service territory. The data loggers were set to log at 5-minute intervals. Guidehouse reset the EWH switch event counter and curtailment timer during the logger installation visit using the IntelliPORT device and readout the event counter and curtailment tier during the retrieval visit.
- **Event scheduling data.** The schedule of events deployed to the EM&V groups.
- **Weather data.** Hourly temperature data provided to Guidehouse by Duke, as well as windspeed data for eight weather stations from the National Oceanic and Atmospheric Administration (NOAA). Windspeed data were collected from weather stations most proximate to the center of the cities contained in Duke's temperature data, and each

participant was mapped to the station closest to their ZIP code. The eight weather stations used can be seen below in Table 2-1.

- **Field verification tracking data.** Data containing records of field verification (or verification) visits that occurred between October 2021 and May 2022. Records include participant account number, device serial number, device type(s), count of devices inspected during the verification visit, and date of verification visit.

Table 2-1: Weather Stations Used Based on Proximity

Weather Station Name	USAF	WBAN
Piedmont Triad International Airport	723170	23170
Raleigh-Durham International Airport	723060	23060
Charlotte/Douglas International Airport	723140	23140
Simmons AAF Airport	746930	46930
Wilmington International Airport	723020	23020
Hickory Regional Airport	723010	23010
Asheville Regional Airport	723150	23150
Greenville-Spartanburg International Airport	723120	23120

Source: Guidehouse analysis

2.2 EM&V Sample Participants, Events, and Data

The estimated impacts presented in this evaluation report are based on the AMI data from a sample of participants drawn from the overall population. This sample of participants was subjected to more events than would be observed by the overall population in a typical year to provide Guidehouse with more data points from which impacts could be estimated. Additionally, the estimated impacts in this report are derived from the sample of participants who received verification visits from Franklin Energy.

Consistent with previous years, Guidehouse developed a random sample of participants with three combinations of switches:

- Water heater switch only;
- Auxiliary heat strip switch only, and;
- Both water heater and auxiliary heat strip switches.

Based on the lessons learned in previous winter studies, the sample included a higher percentage of heat strips and fewer water heaters compared to the program population. After findings from the winter 2020/2021 evaluation indicated potential curtailment failure at the appliance level, Guidehouse recommended Duke contract a third party to inspect the working order of EM&V participants' water heater and heat strips, verifying their health and remediating when necessary. Of the sample of all EM&V participants, Guidehouse selected the 1,017 customers who received verification visits from Franklin Energy, and ultimately excluded one customer due to poor AMI data quality. The final sample of 1,016 participants used to determine ex-post and ex-ante impacts is larger than in previous years, which typically had sample sizes of approximately 800 participants.

Table 2-2 specifies the sample size for each equipment type.

Table 2-2 – EM&V AMI Sample Size

Category	Total EM&V Population	Participants Removed Due To Readdressing Failure*	Participants Removed Because Site Did Not Receive a Verification Visit	Participants Removed Due to Non-Identical Duplicate AMI Data	Final EM&V Analysis Sample
Heat Strip Participants (Groups A & B)	4,245	47	3,553	0	645
Water Heater Participants (Groups C & D)	4,825	21	4,432	1	371
Total (Groups A – D)	**9,070**	**9,002**	**1,017**	**1,016**	**1,016**

* Readdressing indicates a process undertaken in IntelliSource in which EM&V participants are assigned to Group A through Group D. Devices for which this failed were removed from the analysis data to ensure group assignments were correctly represented in the analysis data.

Source: Guidehouse analysis

Guidehouse randomly allocated each EM&V participant site to one of two groups: Group A or Group B (for customers with controlled heat strips) or Group C or Group D (for customers with controlled water heaters). Under this design, when one group (e.g., Group A) is subject to curtailment (for a given event), the other (e.g., Group B) is not, with the group curtailed changing from event to event. This means that only event days need to be included in the analysis, as the group of participants not curtailed on the given event day acts as the control group and the group curtailed acts as the treatment group.

Guidehouse randomly assigned participants to one group or the other using a random ordered pairing based on winter energy usage.[11] The purpose of this approach (discussed in greater detail below) was to minimize the likelihood that the random allocation to groups could result in one group having substantially higher (or lower) consumption patterns than the other. After field verification visits were conducted, the EM&V sample was then reduced to those EM&V participants who received a verification visit from Franklin Energy, as Duke Energy will remove participants from the program who refuse a verification visit.[12]

In addition to these groupings, some customers within Group A and Group B who also had water heaters were chosen by Guidehouse to receive an installation of both water heater and heat strip data loggers by MadDash. The main intention of this was to construct a sample with which Guidehouse could compare impact estimates between AMI and logger data to assess whether models applied to the parallel data streams yield different curtailment estimates. Customers in Group A and Group B that received data loggers were given the additional group designation of E or F, respectively.

[11] After arranging the participants in order of increasing winter energy consumption total, the participants were grouped in pairs. For each pair, the participant with the larger consumption total was randomly assigned to the A or B group, with the lower consumption participant assigned to the opposite group. This was to prevent biasing the A or B group to always have slightly higher consumption.

[12] Since Franklin Energy did not select premises to remediate with respect to the composition of each group (A-D), there was a concern that this would artificially inflate the size of one group over another, thereby affecting the integrity of the original randomization procedure. Guidehouse has determined that the proportion of participants in each group was not materially changed after removing participants who did not receive a verification visit, indicating that the EM&V sample groups continue to represent a randomized control trial (RCT) experimental design.

A key concern of DR evaluations when all participants are subject to the same events is that there remain some non-event days that sufficiently resemble (in terms of temperature and other factors) the event days. This is required to allow for the estimation of a robust baseline. One problem with this approach is that often events are highly correlated with extreme weather conditions, meaning that baselines are often projected out of sample (i.e., baselines are predicted over temperature conditions that may not actually have been observed on non-event days).

Subjecting only half of all EM&V participants to each event ensures the existence of event-like, non-event days in the sample and provides additional information (from the non-curtailed devices) that helps estimate the counterfactual event demand (the baseline). These factors improve model accuracy by substantially reducing the likelihood of model specification bias compared to a purely within-subject[13] approach.

EM&V water heater participants were subjected to 24 water heater DR EM&V events, 12 for Group C, 12 for Group D. EM&V heat strip participants were subjected to 15 heat strip DR events, 8 for Group A, 7 for Group B. Group E was curtailed when either Group A or Group C was curtailed, and Group F was curtailed when either Group B or Group D was curtailed. The date, EM&V group controlled, appliances controlled,[14] and mean event temperature (in °F) are shown in Table 2-3 for water heater participants and Table 2-4 for heat strip participants. All EM&V events began at 7:00 AM and ended at 9:00 AM (prevailing time) except the event on 3/24, which ended at 8:00 AM. A consistent event period was chosen to maximize the precision of estimated impacts and was selected with Duke Energy staff as the period of most interest for projected program capability. All appliances were cycled at 100% (i.e., completely shut off) during the event period.

Table 2-3: Water Heater EM&V Sample Participation

Date	Number of Water Heaters Curtailed*	Temperature (F)	EM&V Group
2/2/2022	14	28	C & E
2/7/2022	25	31	D & F
2/10/2022	35	27	D & F
2/11/2022	30	28	C & E
2/16/2022	42	29	D & F
2/17/2022	38	52	C & E
2/22/2022	47	54	C & E
2/25/2022	67	59	D & F
3/2/2022	74	32	D & F
3/3/2022	64	37	C & E
3/7/2022	76	59	D & F
3/8/2022	66	42	C & E
3/9/2022	78	47	D & F

[13] A “within-subject” approach models customer demand on non-event days to predict the event-day baseline used to estimate impacts. When non-linearities in the temperature/demand relationships exist, this can result in baselines that are too low.

[14] Appliances that informed count of appliances includes only the appliances that received a verification visit from Franklin Energy.

Date	Number of Water Heaters Curtailed*	Temperature (F)	EM&V Group
3/10/2022	69	44	C & E
3/15/2022	85	34	D & F
3/16/2022	72	46	C & E
3/17/2022	90	49	D & F
3/18/2022	76	43	C & E
3/21/2022	79	35	C & E
3/22/2022	93	44	D & F
3/24/2022	90	48	C & E
3/25/2022	106	36	D & F
3/29/2022	114	39	D & F
3/30/2022	102	43	C & E

*Appliances that informed count of appliances includes only the appliances that received a verification visit from Franklin Energy.

Source: Guidehouse analysis

Table 2-4. Heat Strip EM&V Sample Participation

Date	Number of Heat Strips Curtailed*	Temperature (F)	EM&V Group
1/26/2022	283	29	A & E
1/27/2022	285	21	B & F
1/28/2022	283	30	A & E
1/31/2022	287	24	A & E
2/1/2022	288	24	B & F
2/8/2022**	290	31	B & F
2/9/2022**	291	23	A & E
2/14/2022**	291	25	A & E
2/15/2022**	290	21	B & F
2/21/2022	291	29	B & F
2/28/2022	292	34	B & F
3/1/2022	296	32	A & E
3/13/2022	296	17	A & E
3/14/2022	293	31	B & F
3/28/2022	298	33	A & E

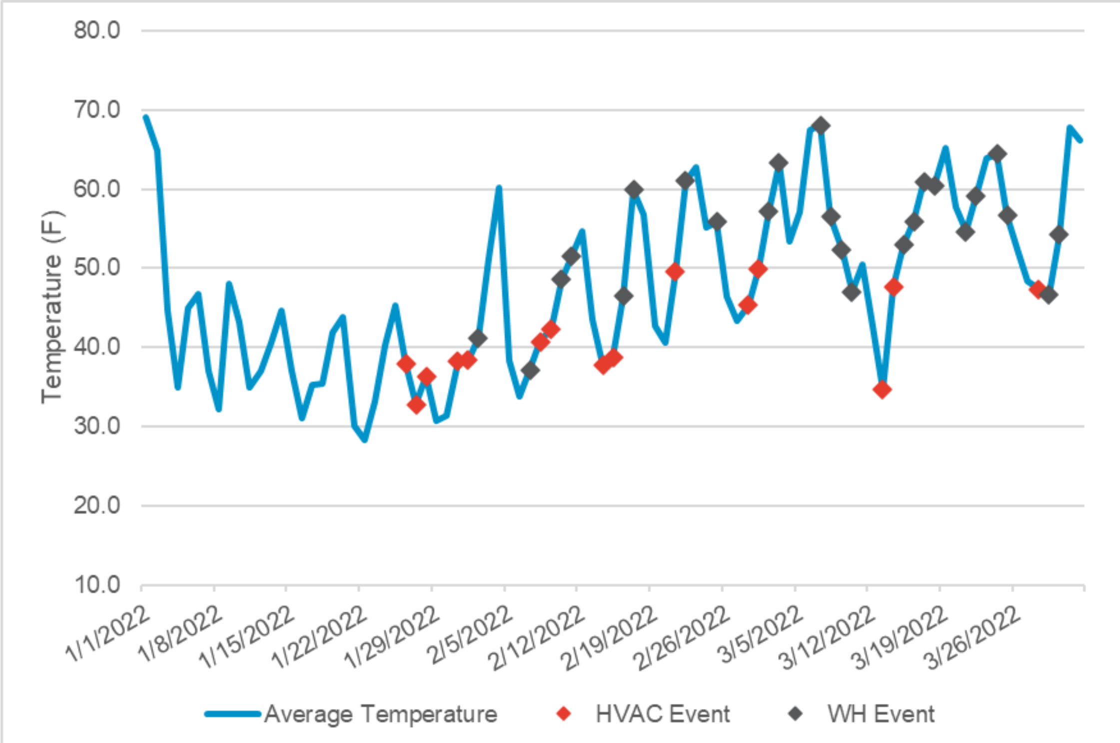
*Appliances that informed count of appliances includes only the appliances that received a verification visit from Franklin Energy.

**Event coincided with a general population event.

Source: Guidehouse analysis

Figure 2-1 illustrates the timing of the EM&V events across the winter. The daily average temperature between 7:00 AM and 9:00 AM (prevailing time) – the average temperature during the event window – is shown as the blue line. Water heater EM&V events are indicated by grey diamonds and heat strip events by red diamonds.

Figure 2-1. Timing and Temperature of EnergyWise DR Events



Sources: Guidehouse analysis

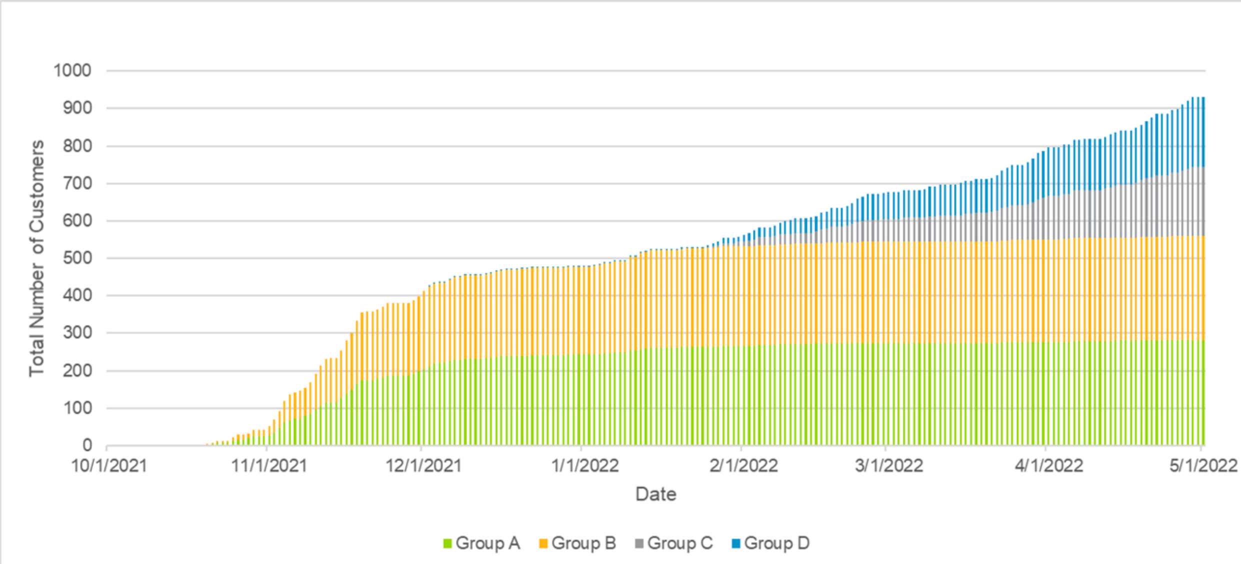
2.3 Contractor Visits and Switch Verification

During the winter 2020/2021 EWH evaluation, field verification evidence from a small sample of participants suggested that in addition to paging issues, switch condition could have been a major driving factor for lower-than-expected curtailment. Duke Energy field verification of heat strip switches noted that a very high proportion of switches appeared to have been disabled by the customer or otherwise improperly installed. These findings were of great concern to both Guidehouse and Duke Energy and, as a result, Duke Energy deemed it necessary to verify that devices controlled by the program were still in working order.

During 2021, Duke Energy worked with Franklin Energy to conduct verification visits of participants enrolled in the EWH program. This entailed an extensive effort of contacting participants to determine whether Franklin Energy could visit the participant's home to verify that equipment was in working order. Once consent to a visit was received, Franklin Energy would arrive on site and verify connectivity between the switch and controlled equipment (i.e., water heater or heat strip) and verify the functionality of controlled equipment. In the event that controlled equipment was not responding as expected, Franklin Energy was to conduct necessary work to ensure that devices were responding appropriately to signals to curtail.

Figure 2-2 indicates the timing of verification visits by EM&V group, which began in the fall of 2021 and continued through the spring of 2022. For participants in EM&V Group A or Group B with a controlled auxiliary heat strip, most verification visits occurred between November and December 2021. For participants in EM&V Group C or D with a controlled water heater, verification visits occurred later, with the majority occurring in the months of February through April 2022. By the end of the winter 2021/2022 season, nearly 10 percent of the EM&V sample had received a field verification visit from Franklin Energy.

Figure 2-2. Cumulative Count of Verification Visits



Source: Guidehouse analysis

2.4 Method for Estimating Capability and Impacts

Guidehouse used an econometric technique known as a fixed effects regression to estimate the impacts of the devices curtailed. Fixed effects regression is a form of linear regression commonly used to estimate the impact of DR programs. The technique is applied to a set of observations of some variable of interest (in this case electricity demand) from several different individuals (i.e., program participants)—also known as longitudinal or panel data—over time.

Fixed effects regression assigns each individual participant[15] its own dummy variable. In this way, Guidehouse may control for each individual's time-invariant characteristics such as the size of a participant's home, its orientation, etc.

Heat strip impacts were estimated as a function of the 3-hour exponential moving average of heating degree quarter-hours and the relative hour of the event (e.g., the first quarter-hour of the event, the second quarter-hour of the event, etc.). Water heater impacts were estimated as a function of the relative quarter hour of each event (e.g., the quarter-hour between 7:00 and 7:15 is the first relative hour, the quarter-hour between 7:15 and 7:30 is the second, etc.). Since all events started at the same time, interacting the treatment effect with the relative quarter hour of each event is analytically equivalent to interacting it with the absolute quarter hour of the day (i.e., the first relative quarter hour is also always the quarter hour between 7:00 and 7:15, etc.).

Formal model specifications with additional input variable detail may be found in Appendix A. Regression Model Specification.

All estimates of uncertainty presented in this report are derived from standard errors that have been clustered at the individual participant level.

[15] In prior years, where appliance-specific logger data were available, these dummy variables – the "fixed effects" that give the approach its name were assigned to individual appliances not participants.

2.5 Method for Estimating Device Responsiveness

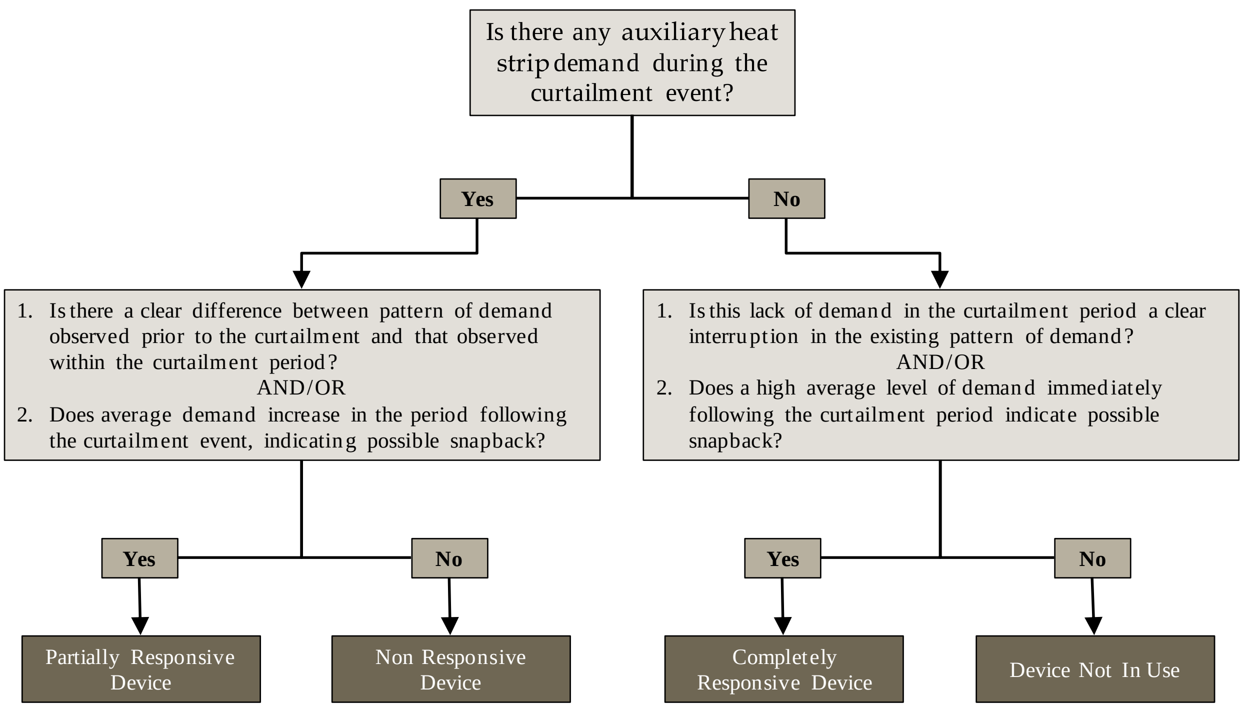
As part of its evaluation of the EWH program, using data collected by appliance loggers, Guidehouse estimated the share of heat strips and water heaters that failed to respond to DEP's curtailment signal. This section provides the details of how this was carried out.

The team assigned heat strips and water heaters to one of the four dispositions defined below:

- **Responsive**: During the given event, the device was completely responsive to the signal to curtail and fully curtailed during the event.
- **Partially Responsive**: During the given event, the device showed evidence of response to the curtailment signal but also showed evidence of some demand occurring during the event.
- **Non-Responsive**: During the given event, the device showed no evidence of response to the curtailment signal.
- **Device Not in Use (DNU)**: During the given event (and in the hours leading up to and following the event), the device showed no evidence of being in use, meaning that even if it were to be responsive, it would not deliver any DR.

Guidehouse assigned the heat strips to each of these categories by examining a data plot of the raw 5-minute interval logger data for each device/curtailment event pair. The team determined assignment for each pair using the decision tree shown in Figure 2-3.

Figure 2-3. Decision Tree for Responsiveness Analysis



Source: Guidehouse

To determine the disposition of water heaters, the evaluation team employed the same approach as described above for heat strips.

3. Impact Findings

The discussion of program impacts on winter demand is divided into the following sections:

- **Historical (Ex-Post) Impacts.** This section provides the estimated impacts of water heater and auxiliary heat strip curtailment during the EM&V events.
- **Forecast Curtailment Capability.** This section provides the estimated DR capability of water heater curtailment across different hours of the morning and auxiliary heat strip curtailment across a variety of different temperatures.
- **Appliance Curtailment Responsiveness.** This section provides a summary of appliance disposition for heat strips and water heaters.
- **Comparison of AMI-Based and Logger-Based Impact Estimates.** This section details the basis for reincorporating logger data into the EM&V process and the results of the side-by-side comparison of AMI-based and logger-based impact estimates.
- **Comparison of Winter 2021/2022 and Winter 2020/2021 Impacts.** This section compares the estimated impacts from this and the prior evaluation, as well as details the results of the investigation into the lower-than-expected impacts estimated during the winter 2020/2021 evaluation.
- **Net-to-Gross.** This section outlines why the appropriate net-to-gross factor for this program should be 1.0.

All impacts reported in this chapter should be considered “at the meter” and should be scaled up by the appropriate loss factor when, for example, determining avoided cost benefits for cost-effectiveness testing. In addition, impacts include only the participants that received a verification visit from Franklin Energy, as Duke Energy will remove customers who refuse a verification visit from the program.

The evaluation calculated the ex-ante estimate of program capability at design conditions, which are 10°F (heat strips) between 7:30 AM and 8:30 AM Eastern prevailing time (water heaters). These capabilities are shown in Table 3-1.

Table 3-1. Program-Wide Impacts

	Appliance Type	Cycling Strategy	Impact per Participant (kW)	Relative Precision +/-% (90% Confidence)	Impact per Appliance (kW)	Total Program Impact (MW)
Projected Capability (Ex-ante)	Heat Strips	100%	0.57	11%	0.53	0.37
	Water Heaters	100%	0.29	16%	0.29	0.28
EM&V Event Impact – Winter 2021/2022 (Ex-post)	Heat Strips	100%	0.31	13%	0.29	0.20
	Water Heaters	100%	0.28	14%	0.27	0.26
Population Event Impact – Winter 2021/2022 (Ex-post)	Heat Strips	100%	0.34	12%	0.32	0.23
	Water Heaters	100%	0.37	11%	0.36	0.36

Note: The program total impact was estimated by calculating the total impact per participant by the number of participants that have received a verification visit from Franklin Energy.

Source: Guidehouse analysis

The principal EM&V impact findings and conclusions regarding the winter event demand impacts for 2021/2022 are as follows:

- **Average estimated impacts and projected capability are higher than estimated in the winter 2020/2021 evaluation.** During EM&V events, Guidehouse estimated average demand reductions of 0.31 kW per heat strip participant and 0.27 kW per water heater participant. These estimates are 0.10 kW and 0.05 kW higher, respectively, than those of the 2020/2021 evaluation. During population events, Guidehouse estimated average demand reductions of 0.34 kW per heat strip participant and 0.37 kW per water heater participant. Guidehouse's projected capability of savings are 0.57 kW per heat strip and 0.29 kW per water heater. In comparison to the winter 2020/2021 evaluation estimates, projected capability has increased by 0.14 kW per heat strip participant and 0.03 kW per water heater participant.
- **The estimated average impact of the winter 2021/2022 EM&V water heater events was 0.27 kW per participant.** This represents the average of the estimated impacts across 24 water heater events taking place between 7:00 and 9:00 in the morning. This average per participant impact is higher than the 0.21 kW per participant that was estimated in winter 2020/2021
- **The estimated average impact of heat strips over the four coldest events during the winter 2021/2022 season was 0.42 kW per participant and 0.39 kW per appliance.** The average temperature across these events was approximately 20°F, with a minimum observed temperature of 17°F.
- **The current DR capability of DEP's EnergyWise program in the winter is approximately 0.64 MW**. Note that this estimate includes only the households that received a verification visit and is the summation of the projected capability of 0.37 MW from heat strip curtailment when the average temperature is 10°F (0.53 kW per appliance) and 0.28 MW from water heater curtailment deployed between 7:30 and 8:30 in the morning (0.29 kW per appliance).
- **There is no statistically significant difference in impact estimates derived from AMI-based data or logger-based data**. One of the principal motivations for reincorporating logger data into this year's evaluation was to confirm the robustness of evaluating DEP EWH impacts from whole-home AMI data and to rule out the theory that the change from appliance-based logger data to whole-home AMI data was responsible for the decrease in savings estimated between the 2017/2018 and 2020/2021 evaluations. Guidehouse confirmed that whole-home AMI data is a valid source of data in determining the impacts of DR events on appliance-level demand and that the magnitude of estimated impacts is comparable between both data sources.

3.1 Historical (Ex-Post) Impacts

The ex-post impacts are the estimated impacts for the actual EM&V events that were called in the winter of 2021/2022. This section is divided into three sub-sections.

1. **Population Event Impacts.** This subsection summarizes the estimated program-level impacts of the five events called for the entire program population
2. **EM&V Event Impacts.** This sub-section summarizes the estimated impacts of 24 water heater events and 15 auxiliary heat strip events called for the EM&V sample.

3. **Load Profile Comparisons.** This subsection provides an illustration of EM&V participant load profiles during events, showing both actual demand and the counterfactual (i.e., the estimated baseline).

3.1.1 Population Event Impacts

The full population of EWH participants was subject to four heat strip events in the winter of 2021/2022. To estimate the population impacts across all four events, Guidehouse applied regression-estimated relationships between temperature and relative event quarter-hour (gathered using EM&V event data) to the temperatures observed during the four population events. The estimated program total (in MW) and average per appliance (in kW) event demand impact for all four curtailment events is provided in Table 3-2 below. It is important to note that from winter 2021/2022 onward, Duke only considers participants who receive a verification visit from Franklin Energy as active program participants, and therefore the program total impact will be significantly lower than in prior reports.

Table 3-2. Heat Strip Population Event Impacts

Date	Event Temperature	Impact per Participant (kW)	Relative Precision +/- % (90% Confidence)	Total Program Impact (MW)
2/8/2022	31	0.20	17%	0.13
2/9/2022	23	0.39	11%	0.25
2/14/2022	25	0.38	11%	0.24
2/15/2022	21	0.41	11%	0.26

Note: The program total impact was estimated by multiplying the average impact per participant by the number of participants that have received a verification visit from Franklin Energy.

Source: Guidehouse analysis

The full population of EWH participants was subject to one water heater event on February 21, spanning 7:00 am through 11:00 am. To determine population event impacts, Guidehouse has historically applied regression estimates from its assessment EM&V event curtailment – which for water heaters is set of quarter-hourly per-participant kW impact estimates – to the quarter-hours over which a population event was in effect. However, since all EM&V events were limited to the period spanning 7:00 am through 9:00 am, this approach is only feasible for determining population impacts for 7:00 am through 9:00 am of the population event, as there are no quarter-hourly impacts to apply to 9:00 am through 11:00 am of the population event.

To work around this issue, Guidehouse adopted the following steps to determine the impact of the one water heater population event:

1. Calculate the average percentage curtailment observed across all quarter-hours of EM&V events.
2. Calculate the average kW (i.e., curtailed kW) per participant during each quarter-hour from 7:00 am through 11:00 am on February 21.
3. Calculate baseline kW per participant (i.e., non-curtailed kW) as the product of (1) the inverse of one minus the average percentage curtailment observed across all quarter-hours of EM&V events and (2) average kW per participant (i.e., curtailed kW) during each quarter hour from 7:00 am through 11:00 am on February 21.

4. Calculate average per-participant curtailment per quarter-hour by calculating the difference in baseline kW per participant (i.e., non-curtailed kW) and average kW per participant during the 7:00 am through 11:00 am window (i.e., curtailed kW).
5. Calculate the average overall per-participant curtailment by calculating the average of (4) across all quarter-hours, then calculate total curtailment by multiplying the average overall per-participant curtailment estimate by the total number of water heaters that received a verification visit by the time of the population event.

The estimated program total (in MW) and average per participant (in kW) DR impact calculated using the approach described above is provided below. As noted above, the program total is significantly lower than in prior years, as Duke will remove participants from the program who refuse a verification visit from Franklin Energy.

Table 3-3. Water Heater Population Event Impacts

Date	Event Timing	Impact per Participant (kW)	Relative Precision +/- % (90% Confidence)	Total Program Impact (MW)
2/21/2022	7:00 am – 11:00 am	0.37	11%	0.36

Note: The program total impact was estimated by multiplying the average impact per participant by the number of participants that have received a verification visit from Franklin Energy.
Source: Guidehouse analysis

3.1.2 EM&V Event Impacts

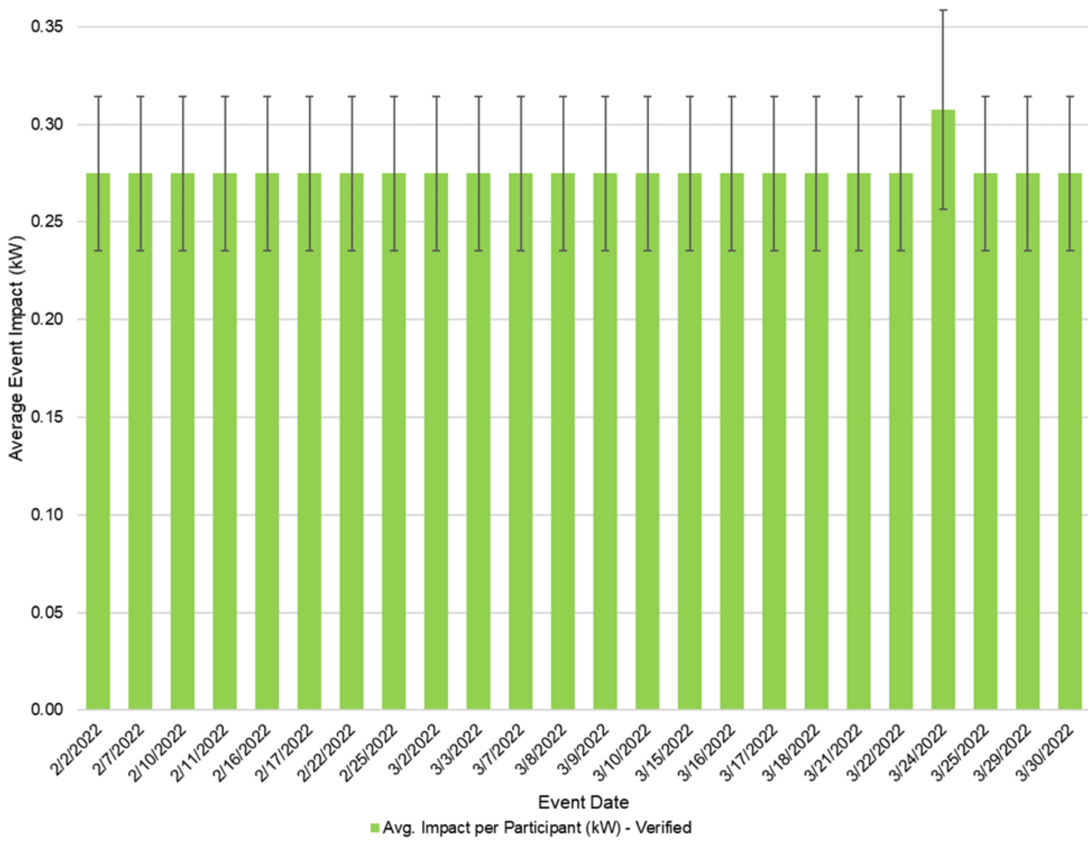
During winter 2021/2022, Duke called 24 EM&V events for water heaters and 15 EM&V events for heat strips. This section contains two subsections that summarize curtailment results for water heaters and heat strips across the EM&V events called. Curtailment results are provided for only those participants who received a verification visit. For a detailed investigation of differences in curtailment outcomes between participants who did or did not receive a verification visit, please reference Appendix B. Comparison of Results Verified vs. Non-Verified Sites.

3.1.2.1 Water Heaters

Figure 3-1 provides a graphical summary of the estimated DR impact of water heater curtailment for 24 EM&V events called in the winter of 2021/2022.[16] Each vertical bar represents the average estimated event impact for participants that received a verification visit from Franklin Energy. The 90% confidence interval is identified by the whiskers. Note that since impacts are estimated as a function only of the relative hour of the event (this is required to project an ex-ante capability by time of day), and all events but the event on March 24 are the same length and cover the same hours, the individual event ex-post estimated impacts are identical for all events except for the event on March 24. The event on March 24 only lasted for one hour (from 7:00 AM to 8:00 AM), and had a higher savings estimate than the other 23 events that were called.

[16] A general population water heater event was called on February 21. This event was omitted from the analysis data because Guidehouse could not compare curtailed and non-curtailed loads for EM&V groups C and D, as all members of groups C and D were called to curtail in the event.

Figure 3-1. Average Water Heater Event Impacts



Note: Per-participant impacts illustrated in this figure are the per-participant impacts for customers who received a verification visit from Franklin Energy.

Source: Guidehouse analysis

The results shown above in Figure 3-1 are also summarized in a tabular fashion in Table 3-4. Similar to the winter 2020/2021 evaluation, all impacts presented above (and below) are inclusive of both responsive *and* non-responsive devices. Moreover, Guidehouse utilized appliance-level logger data to confirm the accuracy of AMI-based estimates and found no statistical difference in impact magnitude. This is discussed in further detail in Section 3.4.

The values are included in Table 3-4, as well as the graphic above may be found in the spreadsheet Appendix D. Demand Response Impacts Spreadsheet, attached as a separate document.

Table 3-4. Average Water Heater EM&V Event Impacts

Event Date	Avg. Event Temperature (°F)	Avg. Impact per Participant (kW)	Relative Precision +/- % (90% Confidence)
2/2/2022	28	0.27	14%
2/7/2022	31	0.27	14%
2/10/2022	27	0.27	14%
2/11/2022	28	0.27	14%
2/16/2022	29	0.27	14%

Event Date	Avg. Event Temperature (°F)	Avg. Impact per Participant (kW)	Relative Precision +/- % (90% Confidence)
2/17/2022	52	0.27	14%
2/22/2022	54	0.27	14%
2/25/2022	59	0.27	14%
3/2/2022	32	0.27	14%
3/3/2022	37	0.27	14%
3/7/2022	59	0.27	14%
3/8/2022	42	0.27	14%
3/9/2022	47	0.27	14%
3/10/2022	44	0.27	14%
3/15/2022	34	0.27	14%
3/16/2022	46	0.27	14%
3/17/2022	49	0.27	14%
3/18/2022	43	0.27	14%
3/21/2022	35	0.27	14%
3/22/2022	44	0.27	14%
3/24/2022	48	0.31	17%
3/25/2022	36	0.27	14%
3/29/2022	39	0.27	14%
3/30/2022	43	0.27	14%
Average of All Events	**41**	**0.28**	**14%**

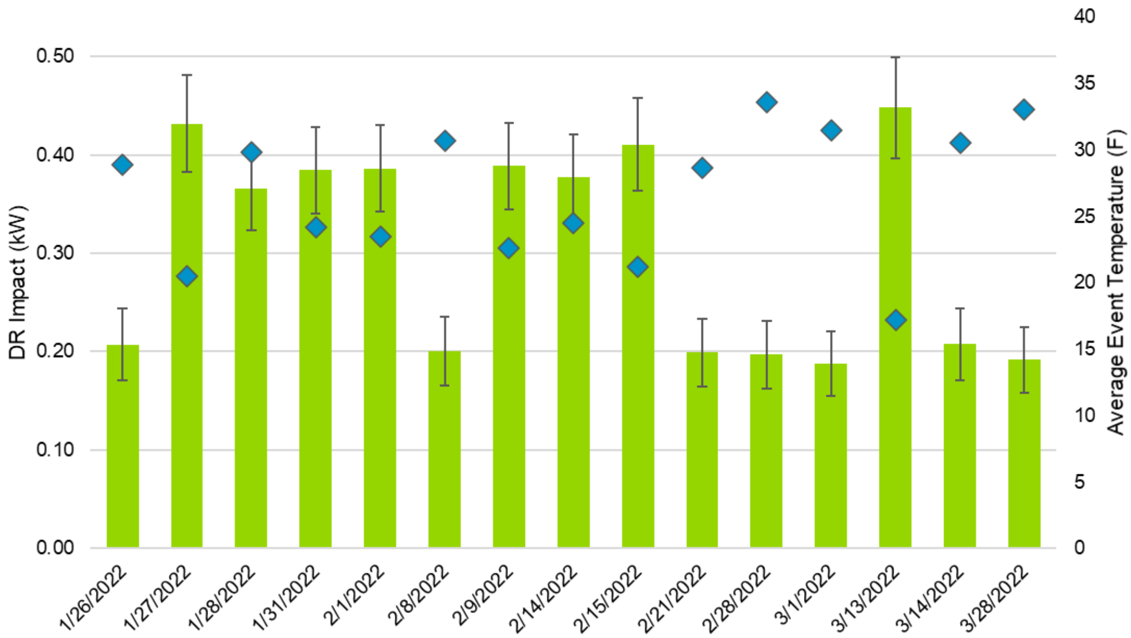
Note: Per-participant impacts illustrated in this table are the per-participant impacts for customers who received a verification visit from Franklin Energy.

Source: Guidehouse analysis

3.1.2.2 Heat Strips

Figure 3-2 provides a graphical summary of the estimated DR impact of heat strip curtailment for all 15 of the events in the winter of 2021/2022. Each vertical bar represents the average estimated event impact for participants that received a verification visit from Franklin Energy. The 90% confidence interval is identified by the whiskers, and the blue diamond (to be read off the right axis) identify the average event dry bulb temperature.

Figure 3-2. Average Heat Strip Event Impacts



Note: Per-participant impacts illustrated in this figure are the per-participant impacts for customers who received a verification visit from Franklin Energy.

Source: Guidehouse analysis

The distribution of the magnitude of impacts across events shown in Figure 3-2 is bimodal. For warmer events with an average event temperature above around 30°F, average impacts tend to cluster around 0.20 kW per participant. For cooler events with an average event temperature below 30°F, average impacts cluster around 0.40 kW per participant. Based on examination of heat strip responsiveness in Section 3.3.1, lower impacts on warmer event days are likely attributed to many heat strips not being in use at the time of those events, which can reduce curtailment capability. In addition, when plotted against average temperatures during the morning period in which winter events are typically called, display a distinct shift upward at around 30°F. This reflects the increasing need of the appliances to use the heat provided by the auxiliary heat strips to supply thermal loads at lower temperatures. In estimating impacts, Guidehouse has controlled for this effect via the use of splines[17] in its regression modeling. This effect is more intuitively visible in the ex-ante capability plots found in Section 3.2, below.

The results shown above in Figure 3-2 are also summarized in a tabular fashion in Table 3-5, below.

[17] Temperature "splines" are an econometric technique for modeling discrete structural breaks in relationships. In this case they are applied to temperatures to capture the non-linear relationship between auxiliary heat strip demand and temperature. Guidehouse has used two splines, implicitly assuming a linear relationship between temperature and demand below 30°F that is different from a linear relationship between temperature and demand above 30°F (i.e., a steeper slope at lower temperatures).

Table 3-5. Average Heat Strip EM&V Event Impacts

Event Date	Avg. Event Temperature (F)	Avg. Impact per Participant (kW)	Relative Precision +/-% (90% Confidence)
1/26/2022	29	0.21	17%
1/27/2022	21	0.43	11%
1/28/2022	30	0.37	11%
1/31/2022	24	0.38	11%
2/1/2022	24	0.39	11%
2/8/2022*	31	0.20	17%
2/9/2022*	23	0.39	11%
2/14/2022*	25	0.38	11%
2/15/2022*	21	0.41	11%
2/21/2022	29	0.20	17%
2/28/2022	34	0.20	17%
3/1/2022	32	0.19	17%
3/13/2022	17	0.45	11%
3/14/2022	31	0.21	17%
3/28/2022	33	0.19	17%
Average of All Events	**27**	**0.31**	**13%**
Average of Coldest Events**	**20**	**0.42**	**11%**

* Events with an asterisk are events that were also called for non-EM&V participants. Per-participant impacts illustrated in this table are the per-participant impacts for customers who received a verification visit from Franklin Energy.

** The coldest events considered are the events with average in-event temperatures at or below 23 degrees Fahrenheit.

Source: Guidehouse analysis and DEP temperature data.

3.1.3 Load Profile Comparisons

It is Guidehouse's standard practice in DR evaluations to provide one or more plots of average actual and counterfactual (i.e., model-predicted baseline) participant demand during DR events. These plots are particularly useful in providing a more intuitive understanding of the processes driving the results presented above. This subsection is divided into two parts. The first part provides the load profile comparison for heat strips, while the second provides the load profile comparison for water heaters.

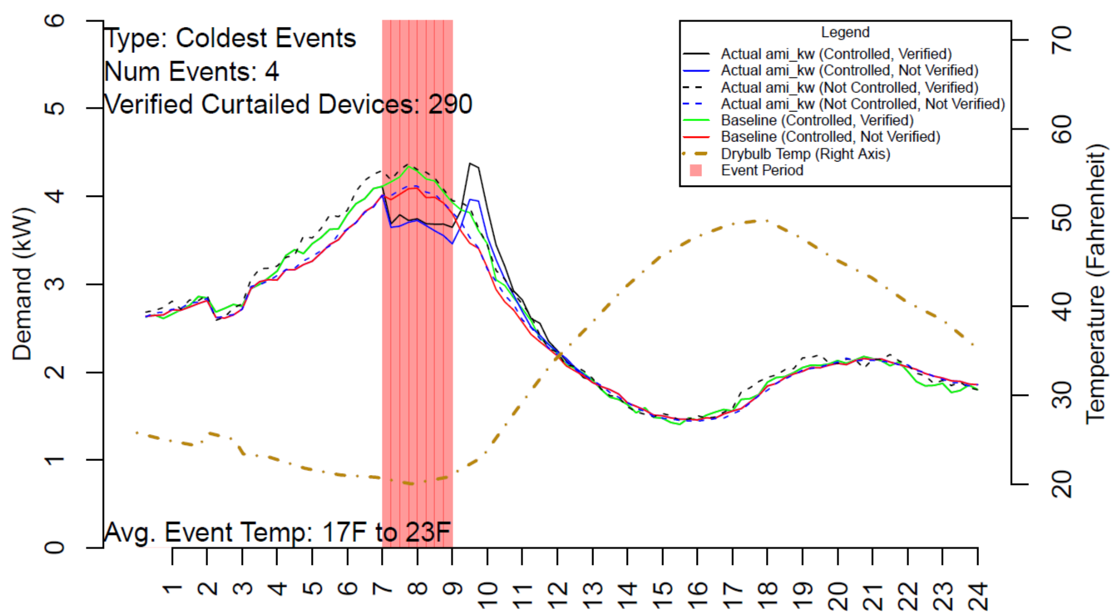
3.1.3.1 Heat Strip Load Profile Comparison

Four examples of event load profile plots for days on which heat strips were curtailed are provided below. The first, Figure 3-3, shows the average load profile associated with the four coldest events observed as part of this study, occurring on January 27, February 9 and 15, and March 13. The coldest average temperature observed across these four events was 17°F (March 13 event), the warmest average temperature observed across these four events was 23°F, and the average temperature across these events was 21°F.

Note that because these profiles are averages across multiple event days (and that Group A and Group B alternated acting as control groups) both the solid line (black and blue) and the dashed line (black and blue) are averages of the loads of participants in both Group A and B. Readers can interpret the lines provided on the plot as follows:

- The **solid black line** indicates average participant demand for those participants whose heat strips were curtailed *and* who received a verification visit from Franklin Energy.
- The **solid blue line** indicates average participant demand for those participants whose heat strips were curtailed *and* who *did not* receive a verification visit from Franklin Energy.
- The **dashed black line** shows the actual average heat strip load of the control group of participants who received a verification visit from Franklin Energy.
- The **dashed blue line** shows the actual average heat strip load of the control group of participants who *did not* receive a verification visit from Franklin Energy.
- The **solid green line** is what the model predicts demand would have been had no event been called for customers who received a verification visit from Franklin Energy. This is baseline, or counterfactual, heat strip participant demand, for *remediated* (i.e., verified) participants.
- The **solid red line** is what the model predicts demand would have been had no event been called for customers who *did not* receive a verification visit from Franklin Energy. This is baseline, or counterfactual, heat strip participant demand, for *non-remediated* (i.e., non-verified) participants.
- The **dash-dotted yellow line** shows the average outdoor temperature (right axis).

Figure 3-3. Heat Strip Load Shape Comparison: Four Coldest Days



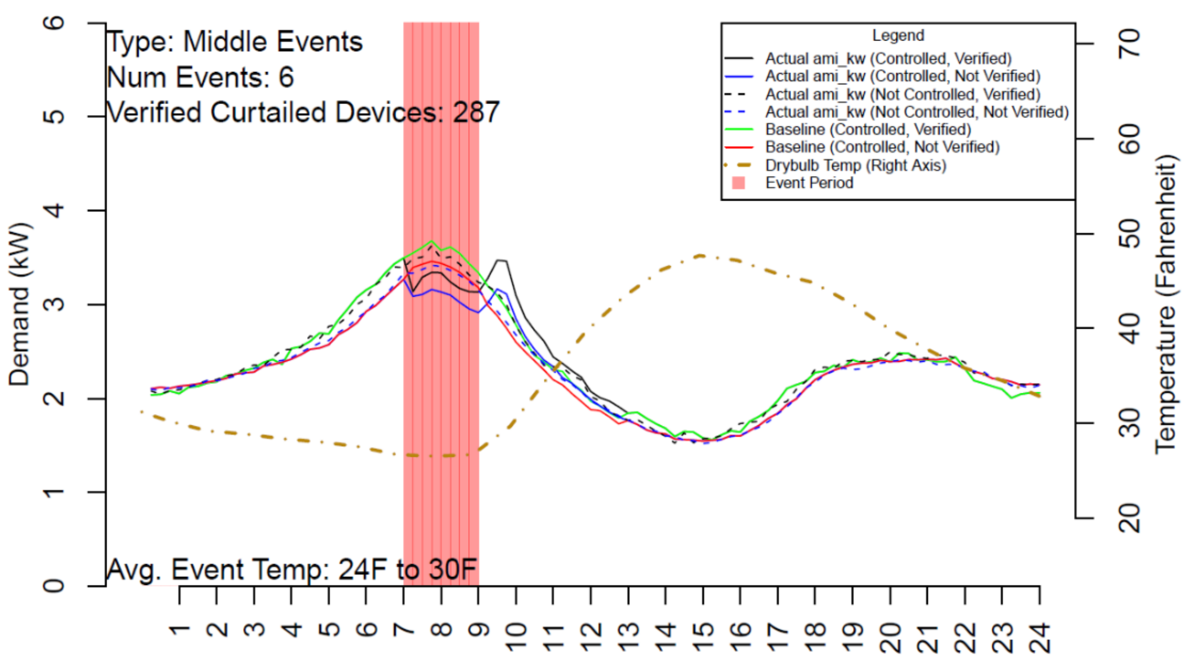
Source: Guidehouse analysis

Colder events are expected to generate greater demand reduction impacts. This relationship can be seen in the relative magnitude of the dip in demand during the event window, in comparison to the following plots, which depict impacts during the middle-temperature and hottest events, respectively. As expected, actual curtailed AMI kW drops during the event window and rises thereafter, consistent with expected in-event kW reductions and post-event snapback.

Of note is the observation that participants who received a verification visit from Franklin Energy appear to have had both greater consumption relative to non-remediated sites (baseline) and a higher absolute-level of curtailment during events (impacts) as compared to participants who did not receive a verification visit. Guidehouse investigated discrepancies in underlying consumption with a statistical test of differences in average kW between remediated-and-non-curtailed participants and non-remediated-and-non-curtailed participants and found statistically significant differences in the level of kW demand for several of the quarter hours leading up to and after DR events. As such, Guidehouse included additional explanatory variables in the regression models employed to control for underlying differences in demand between customers who received a verification visit and those who did not receive a verification visit, the details of which can be found in Appendix A. Regression Model Specification. Guidehouse also provides additional comparisons of impacts between the two subgroups of participants in Appendix B. Comparison of Results Verified vs. Non-Verified Sites.

The second example, Figure 3-4, shows the average load profile associated with the six "middle" temperature events observed as part of this study, occurring on January 26, 28, and 31, and February 1, 14, and 21. The coldest average temperature observed across these events was 24°F, the warmest average temperature observed across these events was 30°F, and the average temperature across these events was 27°F. Similar to the prior figure, customers that received a verification visit had greater underlying loads in winter 2021/2022 as compared to customers that did not receive a verification visit. However, it appears that the two subgroups of participants have similar reductions in kW demand during middle temperature event days.

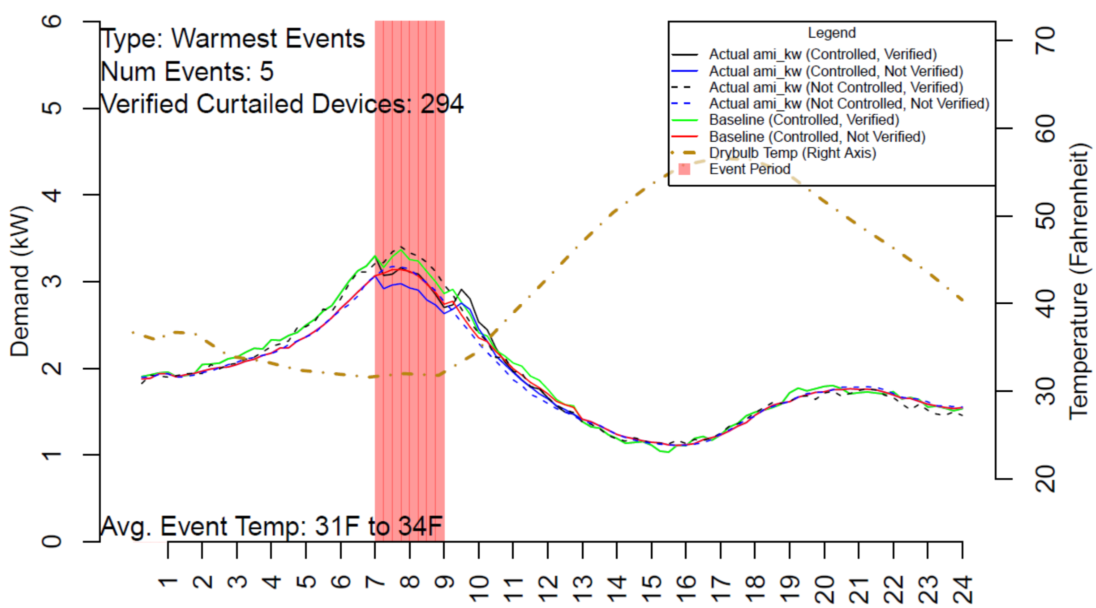
Figure 3-4. Heat Strip Load Shape Comparison: Six Middle Temperature Days



Source: Guidehouse analysis

The third example, Figure 3-5, shows the average load profile associated with the five warmest temperature events observed as part of this study, occurring on February 8 and 28, and March 1, 14, and 28. The coldest average temperature observed across these events was 31°F, the warmest average temperature observed across these five events was 34°F, and the average temperature across these events was 32°F. As was the case for the prior two figures, customers that received a verification visit had greater underlying loads in winter 2021/2022 as compared to customers that did not receive a verification visit. In addition, similar to what was observed for the six middle temperature events, it appears that the two subgroups of participants have similar reductions in kW demand during the five warmest event days.

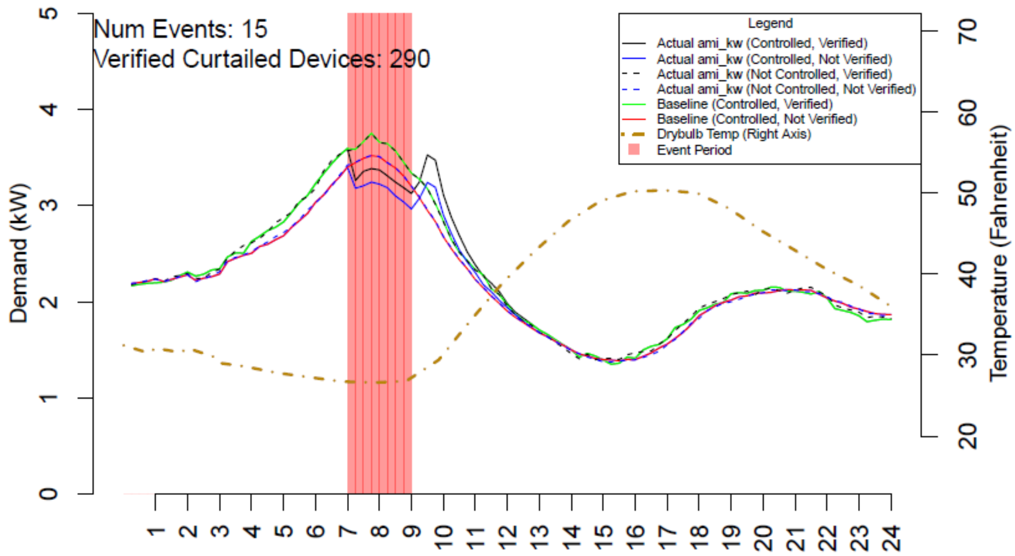
Figure 3-5. Heat Strip Load Shape Comparison: Five Warmest Days



Source: Guidehouse analysis

As a final point of reference, below in Figure 3-6 is a plot of the quarter-hourly heat strip event impacts averaged over all 15 heat strip EM&V event days of this season. Unlike the above plots, which segmented event impacts by temperature range, this plot incorporates impacts from the full range of observed temperatures. This significantly increases the size of the sample and effectively smooths out intra-hourly variation in baseline electrical demand caused by swings in temperature. Accordingly, the estimated baseline values track almost perfectly with the actual kW demand during the event window. Similar patterns hold when looking across all events - participants who received a verification visit from Franklin Energy appear to have had both greater consumption relative to non-remediated sites (baseline). In addition, similar to what was observed across the middle temperature and warmest events, it appears that the absolute level of curtailment during events is similar between the two subgroups. Guidehouse provides additional comparisons of impacts between the two subgroups of participants in Appendix B. Comparison of Results Verified vs. Non-Verified Sites.

Figure 3-6. Heat Strip Load Shape Comparison: All Events



Source: Guidehouse analysis

The four load profiles above, as well as a separate load profile for each individual event day, may all be found in Appendix F. Heat Strip Load Shapes, under a separate cover.

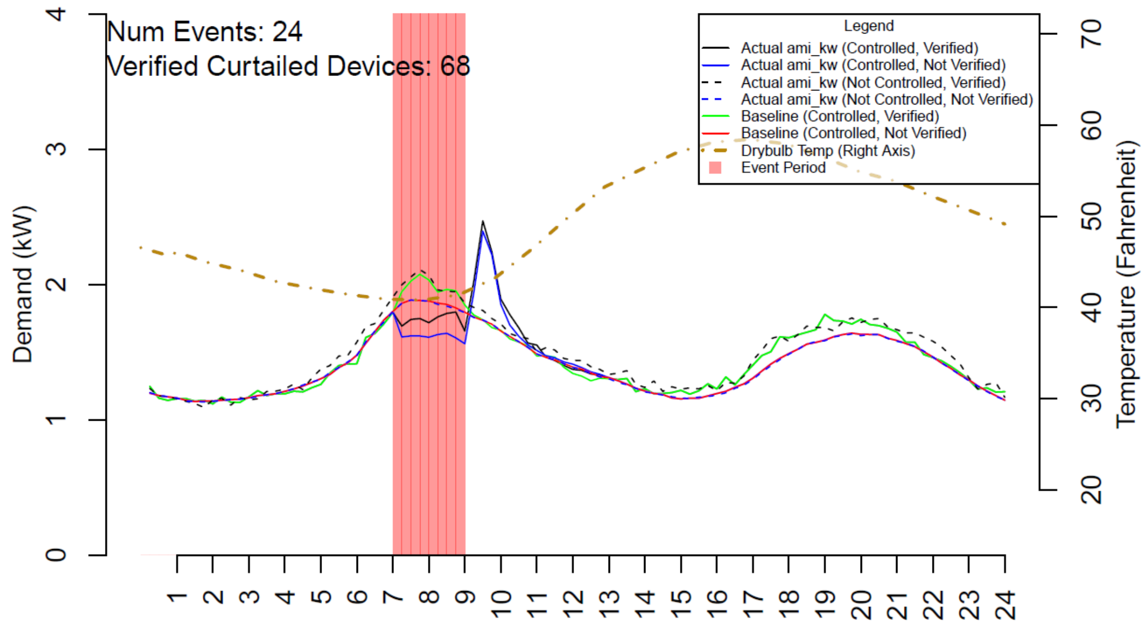
3.1.3.2 Water Heater Load Profile Comparison

Since water heater DR impacts do not materially fluctuate with daily changes in temperature, Guidehouse has included a single example load profile below. Figure 3-7 shows the average load profiles across 24 water heater event days. Note that because these profiles are averages across multiple event days (and that Group C and Group D alternated acting as control groups) both the solid black line and the dashed black line are averages of the loads of participants in both Group C and D. Similar to what was provided for heat strips, readers can interpret the lines provided on the plot as follows:

- The **solid black line** indicates average participant demand for those participants whose water heaters were curtailed *and* who received a verification visit from Franklin Energy.
- The **solid blue line** indicates average participant demand for those participants whose water heaters were curtailed *and* who *did not* receive a verification visit from Franklin Energy.
- The **dashed black line** shows the actual average water heater load of the control group of participants who received a verification visit from Franklin Energy.
- The **dashed blue line** shows the actual average water heater load of the control group of participants who *did not* receive a verification visit from Franklin Energy.
- The **solid green line** is what the model predicts demand would have been had no event been called for customers who received a verification visit from Franklin Energy. This is baseline, or counterfactual, water heater participant demand, for *remediated* (i.e., verified) participants.

- The **solid red line** is what the model predicts demand would have been had no event been called for customers who *did not* receive a verification visit from Franklin Energy. This is baseline, or counterfactual, water heater participant demand, for *non-remediated* (i.e., non-verified) participants.
- The **dash-dotted yellow line** shows the average outdoor temperature (right axis).

Figure 3-7. Water Heater Load Shape Comparison: Average of All Event Days



Source: Guidehouse analysis

Similar to what was observed for heat strips, the load profile plot above shows that participants who received a verification visit from Franklin Energy appear to have had both greater consumption relative to non-verified sites and a similar absolute-level of curtailment during events as participants who did not receive a verification visit. Given this, Guidehouse included additional explanatory variables in the water heater regression model to control for the greater underlying demand of customers who received a verification visit. Guidehouse provides additional comparisons of impacts between the two subgroups of participants in Appendix B. Comparison of Results Verified vs. Non-Verified Sites.

The load profile above, as well as a separate load profile for each individual event day, may all be found in Appendix E. Water Heater Load Shapes, under a separate cover.

3.2 Forecast Curtailment Capability

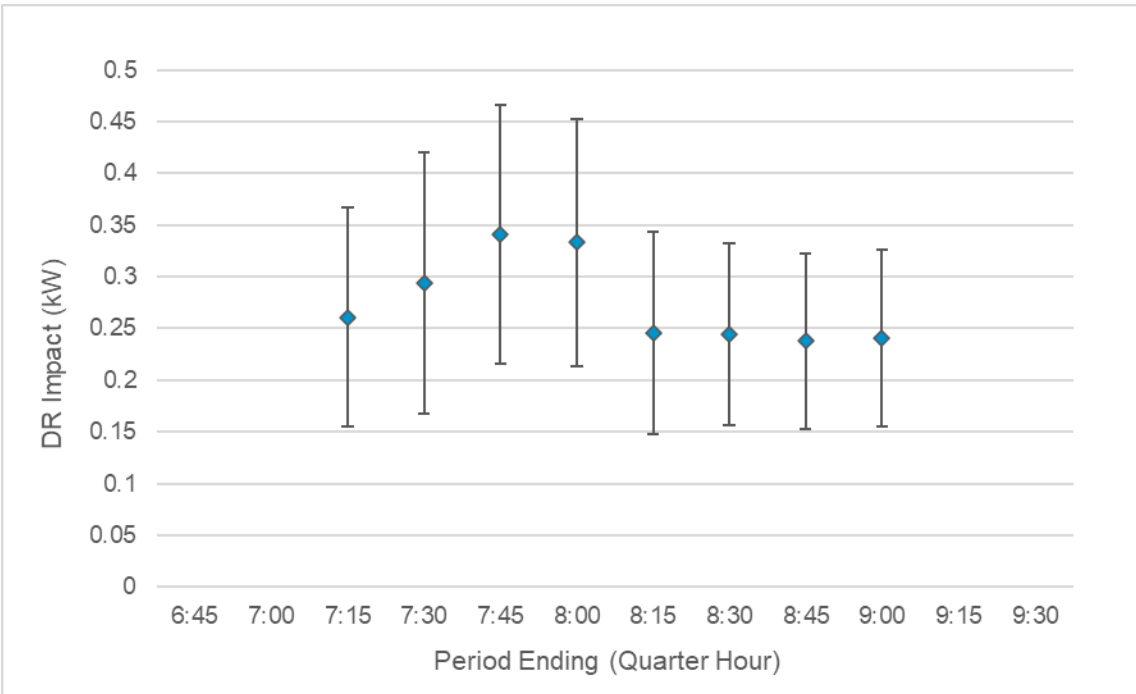
This section provides the estimated EWH DR capability (ex-ante impacts). These estimates are Guidehouse's projection of how much DR the program could offer under a range of different possible temperatures. This estimate of capability is based on the regression-estimated relationships between DR impacts and outdoor temperature from which the ex-post impacts were also developed.

This section is divided into two subsections: the first details the projected DR capability of water heaters at different times of day, and the second details the projected DR capability of heat strips under different weather conditions. Guidehouse provides a separate comparison of the winter 2020/2021 and winter 2021/2022 ex-ante heat strip capability in Section 3.5.

3.2.1 Water Heater DR Capability

Water heater impacts are modeled as a function of the time of day in which curtailment occurs. Figure 3-8 provides the average estimated impact per remediated water heater participant (i.e., per verified participant) in each of the quarter-hours of the day included in EM&V events deployed for the 2021/2022 winter evaluation. The blue diamonds represent the average estimated impact at each quarter-hour of the day and correspond to the values used to calculate the impacts of each of the EM&V events. The whiskers capture the 90% confidence interval.

Figure 3-8. Projected Average DR Capability per Water Heater Participant



Note: Capability estimates are presented for participants that received a verification visit from Franklin Energy.
Source: Guidehouse analysis

Notable in the figure above, based on winter 2021/2022 events called, capability estimates indicate greatest curtailment capability in the first hour of a water heater event. In that first hour of a water heater event, capability estimates show that curtailment could range from 0.25 to 0.34 kW per participant. After the first hour of an event, curtailment could be approximately 0.24 kW per participant. The water heater capability estimate for the coincident peak period (e.g., between 7:30 and 8:30 in the morning) is 0.30 kW per participant.

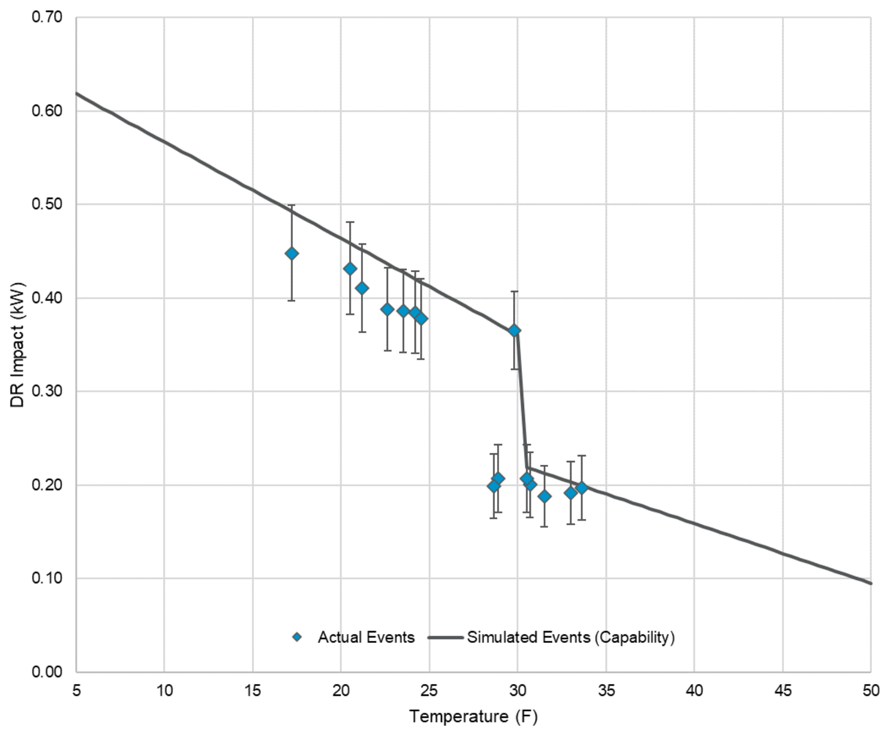
3.2.2 Heat Strip DR Capability

This subsection provides the projected capability of heat strips. This capability is projected by applying a series of temperature values to the estimated model parameters for participants that received a verification visit from Franklin Energy. Guidehouse's projected capability (shown in

Figure 3-9) assumes that the temperature at which the capability is estimated lasts the entire length of the event and is the same as the temperature in the three hours leading up to the event.[18]

Figure 3-9 provides the average projected capability of remediated participants (i.e., verified participants) with curtailable heat strips from 5°F to 50°F (grey line). Actual estimated EM&V event impacts are represented on this chart as blue diamonds, with the 90% confidence interval around each estimate represented by the whiskers. The values underlying this plot may be found in the Appendix D. Demand Response Impacts Spreadsheet that accompanies this report.

Figure 3-9. Projected Average DR Capability per Heat Strip Participant[19]



Note: Capability estimates are presented for participants that received a verification visit from Franklin Energy. Also note that the average 3-hour exponential moving average of temperature is higher than the average event temperature shown on the graph, which is why the actual events trend slightly below the projected average line.
Source: Guidehouse analysis

Heat strip capability estimates range from around 0.62 kW at 5°F to 0.09 kW at 50°F, with the capability of heat strips showing a significant discontinuity at 30°F. This discontinuity reflects the nonlinear nature of heat strip demand as a function of temperature, which is captured in the model by two temperature splines (for more details, please refer to Appendix A. Regression Model Specification). This hinge-point for the splines – i.e., the threshold above which the

[18] This assumption is required due to the way impacts are estimated. Heat strip DR impacts were modeled, in part, as a function of the exponential moving average of heating degree quarter-hours. As such, Guidehouse's projected capability assumes that the temperature at which the capability is estimated lasts the entire length of the event and is the same as the temperature in the three hours leading up to the event.

[19] Note that the average 3-hour exponential moving average of temperature is higher than the average event temperature shown on the graph, which is why the actual events trend slightly below the projected average line.

relationship between temperature and demand impacts becomes much steeper – was set at 30°F based on analysis of appliance-specific loads on very cold non-event days conducted as part of the 2017/2018 evaluation.

Duke should exercise caution when considering projected capability that is some distance outside the range of observed temperatures. Guidehouse has projected impacts implied by the regression-estimated parameters for temperatures as low as 5°F, which is far below the lowest event temperature observed in the winter of 2021/2022 (17°F on March 13th). Typically, Guidehouse would project capability only out to 5°F beyond the lowest (and highest) observed event temperatures due to dangers of predicting far outside of the observed sample. However, to be consistent with the temperature range used for reporting ex-ante impacts in previous evaluations, Guidehouse has extended its estimates of ex-ante impacts to as low as 5°F and as high as 50°F.

3.3 Appliance Curtailment Responsiveness

A primary motivation for including appliance-based logger data in this year's evaluation was to confirm that the shift from this data source to whole-home AMI was not responsible for the lower-than-expected impact results estimated in the winter 2020/2021 evaluation. Another primary motivation for reincorporating logger data into this year's evaluation was to explore the role curtailment failure may have played in the lower-than-expected impacts identified in the winter 2020/2021 report. In that report, the main theory for the small impacts was a high rate of appliance-level curtailment failure but, because only whole-home AMI data was available, it was not possible to investigate this claim.

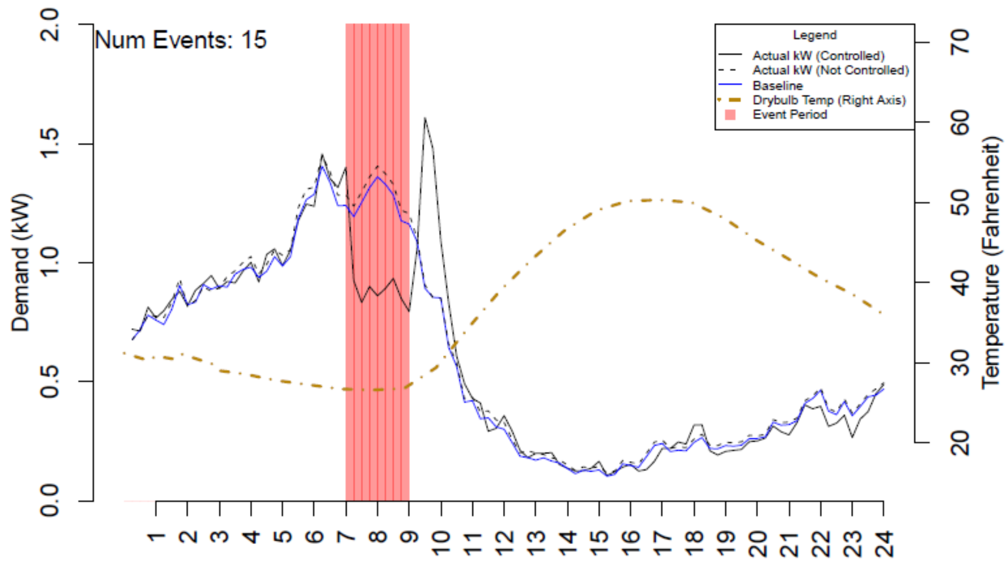
The section explores Guidehouse analysis of appliance curtailment responsiveness for the sites that received appliance loggers. This analysis is first provided for heat strips and then for water heaters.

3.3.1 Heat Strip Curtailment Responsiveness

This subsection presents Guidehouse analysis of appliance curtailment responsiveness for heat strips at sites that had received an appliance logger and a site verification visit from Franklin Energy. Figure 3-10 below presents quarter-hourly heat strip demand collected from appliance loggers and averaged over all 15 heat strip EM&V event days. Heat strips participating in a DR event are supposed to fully curtail when called upon. As such, Guidehouse expects to see kW demand drop to near zero during a DR event.[20] However, referencing appliance logger data for EM&V participants that received a verification visit, many heat strips were still not functioning during at least one heat strip event. Based on these findings, Guidehouse undertook an analysis of device responsiveness (e.g., classifying devices as fully responsive, partially responsive, non-responsive, or not in use) following the approach highlighted in Section 2.5.

[20] Guidehouse expects a certain portion of heat strips to engage for emergency defrost during particularly cold events, although the kW demand for defrost is typically low and intermittent.

Figure 3-10. Heat Strip Load Shape Comparison: All Events (Logger Data)

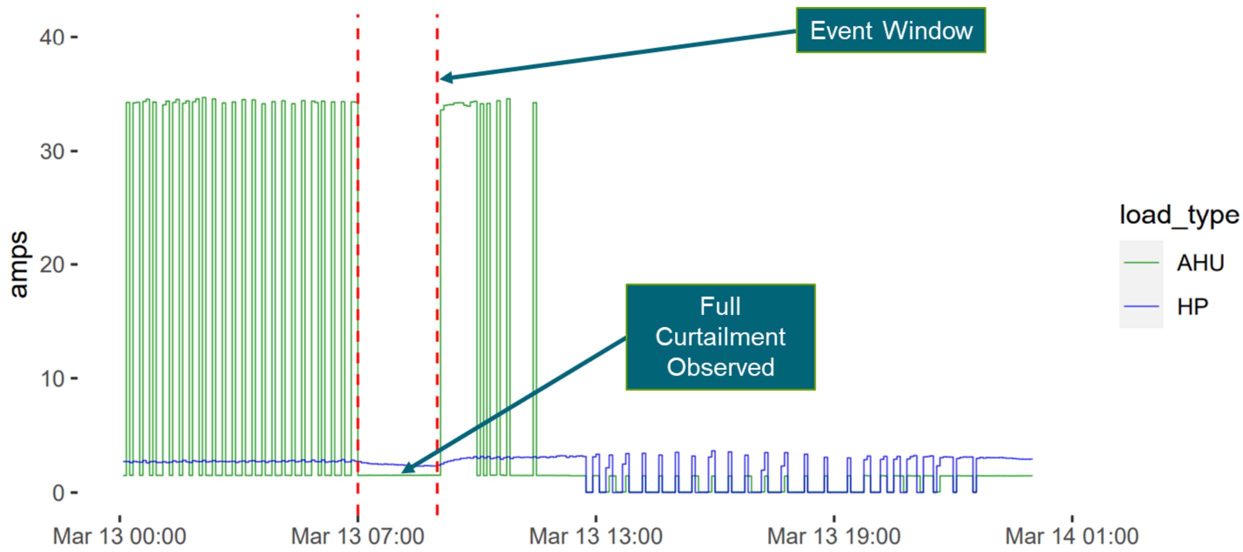


Note: Load shapes are presented for participants that received a verification visit from Franklin Energy and an appliance data logger from MadDash.

Source: Guidehouse analysis

As an illustration of Guidehouse's classification approach, Figure 3-11 presents a heat strip profile for a device reviewed by Guidehouse and deemed fully responsive to an event. This profile includes observed amperage recorded from a site's air handling unit (labeled AHU in the figure below) and observed amperage recorded from a site's heat pump (labeled HP in the figure below). When an auxiliary heat strip is engaged, amperage collected from the air handling unit will typically rise to between 30 and 40 amps. When a heat strip is not engaged, amperage will typically cycle between zero and less than 5 amps, with non-zero amperage corresponding to times where the heat pump is engaged and the air handling unit's fan is running to circulate air. In this plot, during the event window bounded by red-dashed lines, the site undergoes curtailment, with the auxiliary heat strip engaged in numerous intervals leading up to the event (seen as cycling between zero and 35 amps), then dropping to near-zero during event hours. After the event, there is a period of prolonged amperage drawn for a period spanning one hour, consistent with post-event snapback typically observed at the close of a DR event.

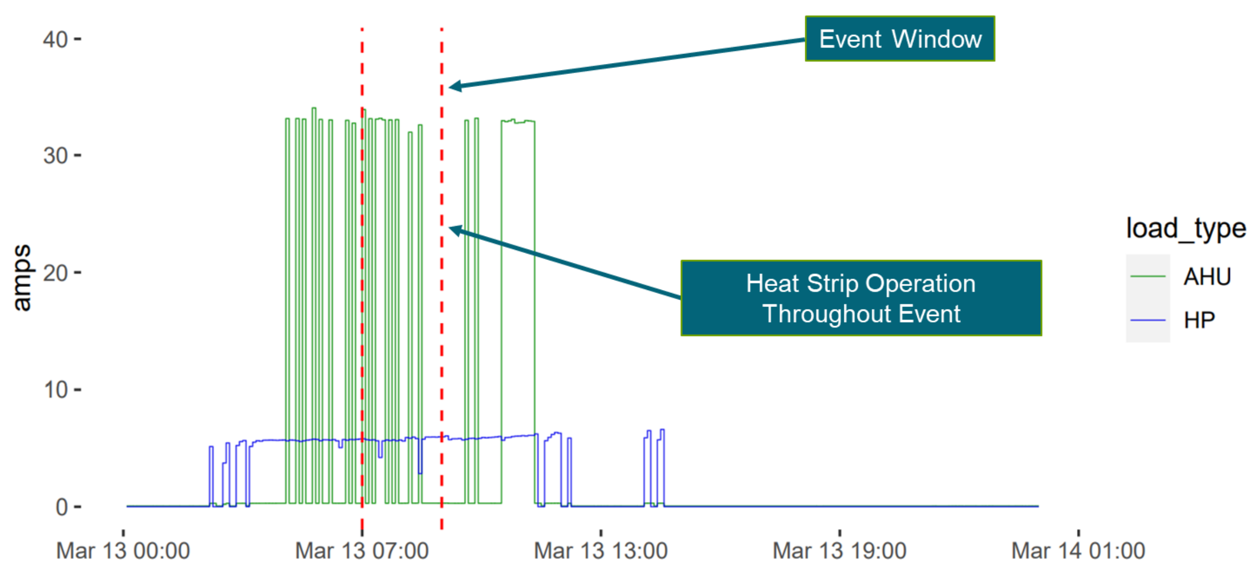
Figure 3-11. Heat Strip Profile for a Fully Responsive Device



Source: Guidehouse analysis

As a point of comparison, Figure 3-12 presents a heat strip profile for a device reviewed by Guidehouse and deemed non-responsive during an event. Similar to the prior figure, this profile includes observed amperage recorded from a site's air handling unit (labeled AHU in the figure below) and observed amperage recorded from a site's heat pump (labeled HP in the figure below). Notable for this site, however, is the continued operation of the auxiliary heat strip during the event window (bounded by red-dashed lines).

Figure 3-12. Heat Strip Profile for a Non-Responsive Device



Source: Guidehouse analysis

Results from Guidehouse's analysis of heat strip responsiveness at the time of an event are summarized on a per-event basis in Table 3-6 below. Based on this analysis, Guidehouse identified a substantial number of devices that were not in use at the time of an event, which tended to occur on warmer event days, such as March 28 where 62% of devices were not in use leading up to or following an event. On average, 41% of devices were not in use at the time of an event across all event days, and 32% of devices were not in use on the coldest event days. In addition to the number of devices not in use, at least one-third of heat strips in the logger sample were deemed non-responsive (i.e., not curtailed during events). Non-responsiveness was more pronounced on the coldest four event days. On average, around one-quarter to one-third of heat strips in the logger sample were deemed at least partially responsive (i.e., exhibited at least some curtailment during events).

Table 3-6. Heat Strip Responsiveness in Curtailment Events – Logger Sample

Event Date	Average Event Temperature (F)	Average Impact per Logger Participant (kW)*	Device Not Used (%)	Non-Responsive (%)	Partially Responsive (%)	Completely Responsive (%)
1/26/2022	29	0.21	43%	25%	10%	23%
1/27/2022	21	0.43	27%	37%	7%	29%
1/28/2022	30	0.37	50%	18%	15%	18%
1/31/2022	24	0.38	35%	35%	0%	30%
2/1/2022	24	0.39	39%	41%	7%	12%
2/8/2022	31	0.20	49%	22%	10%	20%
2/9/2022	23	0.39	33%	45%	3%	20%
2/14/2022	25	0.38	53%	25%	5%	18%
2/15/2022	21	0.41	34%	39%	5%	22%
2/21/2022	29	0.20	46%	44%	2%	7%
2/28/2022	34	0.20	29%	32%	12%	27%
3/1/2022	32	0.19	48%	28%	0%	25%
3/13/2022	17	0.45	33%	33%	10%	25%
3/14/2022	31	0.21	32%	41%	10%	17%
3/28/2022	33	0.19	62%	28%	0%	10%
All Events	**27**	**0.31**	**41%**	**33%**	**6%**	**20%**
Coldest Events**	**21**	**0.42**	**32%**	**39%**	**6%**	**24%**

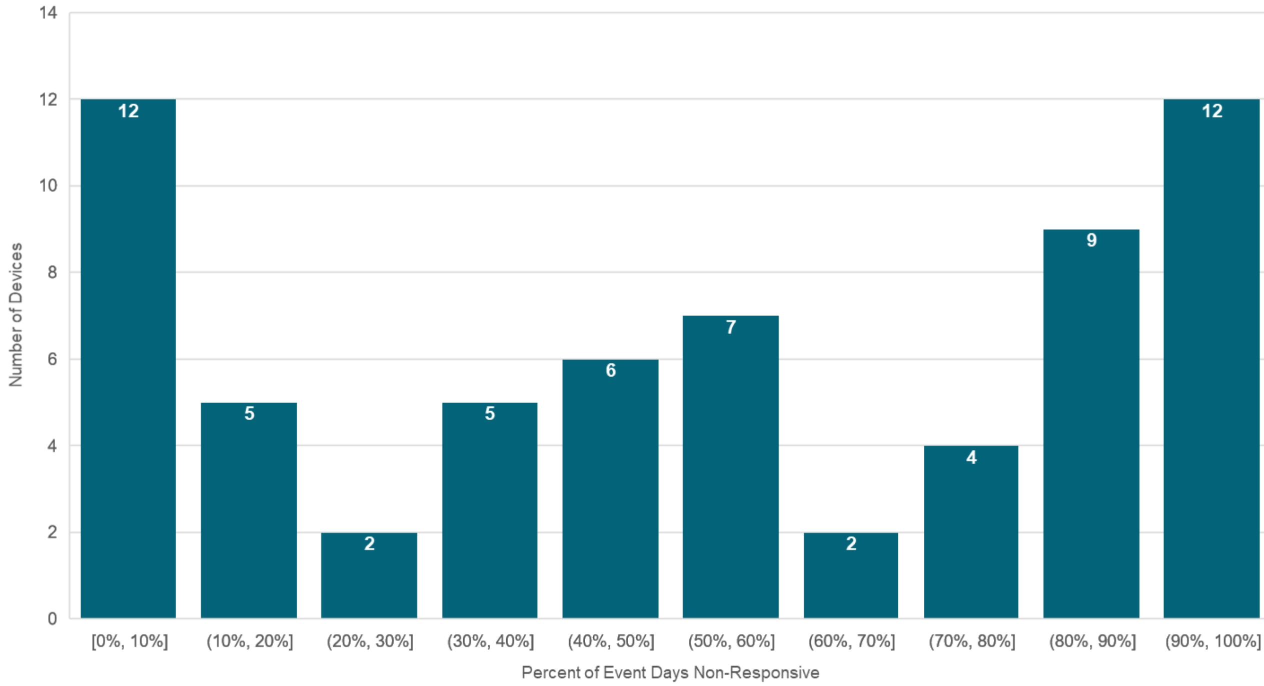
* Per-participant impacts illustrated in this table are the per-participant impacts for customers who received a verification visit from Franklin Energy and an appliance data logger from MadDash

** The coldest events considered are the events with average in-event temperatures at or below 23 degrees Fahrenheit.

Source: Guidehouse analysis

Figure 3-13 below presents a histogram of devices segmented by the percentage of events in which they failed to respond to the curtailment signal. The distribution suggests that, while a handful of devices curtail some of the time (the middle of the distribution), most of the devices in the sample either curtail almost all of the time (left-hand side of distribution) or almost none of the time (right-hand side of distribution). A more thorough discussion of the non-responsiveness of heat strip devices, as well as a comparison to the winter 2020/2021 evaluation, can be found in Section 3.5.2.

Figure 3-13. Percent of Event Days Non-Responsive per Heat Strip in Logger Sample



Source: Guidehouse analysis

3.3.2 Water Heater Curtailment Responsiveness

This subsection presents Guidehouse analysis of appliance curtailment responsiveness for water heaters at sites that had received an appliance logger and a site verification visit from Franklin Energy. In contrast to the high variability of heat strip curtailment responsiveness, water heaters appear far more often to respond to curtailment signals. As seen in Table 3-7, on average roughly 70% of water heaters were deemed at least partially responsive to curtailment signals, while only 10% were deemed non-responsive (the remaining 20% were never in use at the time of an event).

Table 3-7. Water Heater Responsiveness in Curtailment Events – Logger Sample

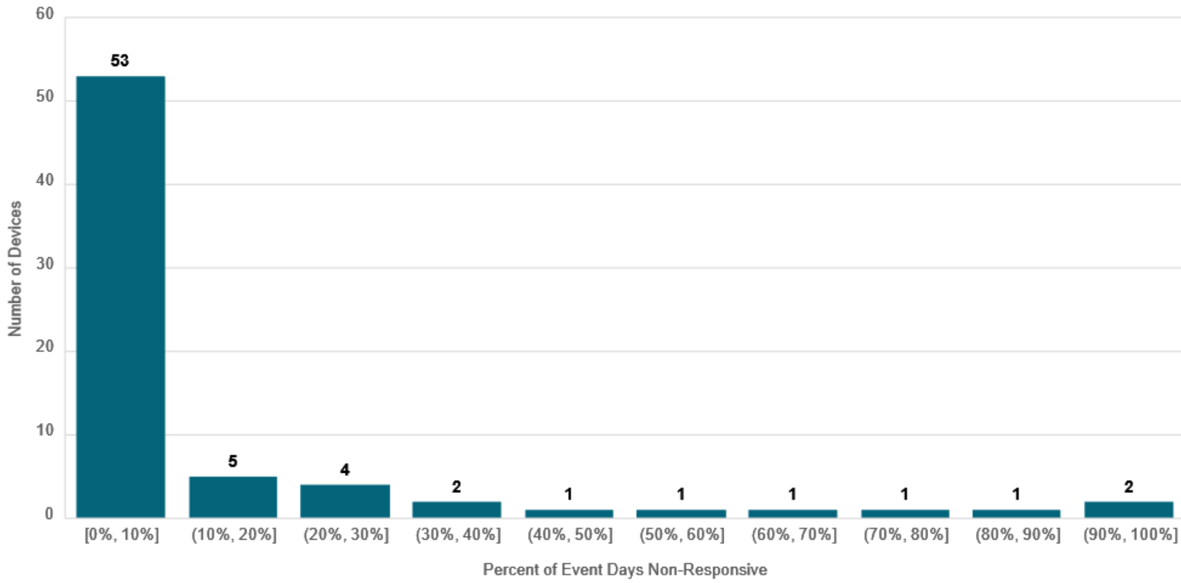
Event Date	Average Impact per Logger Participant (kW)	Device Not Used (%)	Non-Responsive (%)	Partially Responsive (%)	Completely Responsive (%)
2/2/2022	0.27	20%	5%	50%	25%
2/7/2022	0.27	11%	23%	23%	43%
2/10/2022	0.27	31%	11%	34%	23%
2/11/2022	0.27	18%	8%	50%	25%
2/16/2022	0.27	17%	17%	43%	23%
2/17/2022	0.27	18%	5%	50%	28%
2/22/2022	0.27	20%	8%	48%	25%
2/25/2022	0.27	17%	14%	43%	26%
3/2/2022	0.27	17%	14%	43%	26%
3/3/2022	0.27	23%	10%	60%	8%
3/7/2022	0.27	20%	11%	37%	31%
3/8/2022	0.27	20%	10%	60%	10%
3/9/2022	0.27	17%	6%	57%	20%
3/10/2022	0.27	18%	8%	65%	10%
3/15/2022	0.27	11%	3%	54%	31%
3/16/2022	0.27	28%	8%	58%	8%
3/17/2022	0.27	31%	6%	51%	11%
3/18/2022	0.27	20%	5%	65%	10%
3/21/2022	0.27	13%	13%	60%	15%
3/22/2022	0.27	20%	9%	49%	23%
3/24/2022	0.31	33%	0%	60%	8%
3/25/2022	0.27	26%	40%	31%	3%
3/29/2022	0.27	35%	12%	35%	18%
3/30/2022	0.27	22%	0%	67%	11%
All Events	**0.28**	**21%**	**10%**	**50%**	**19%**

Note: Per-participant impacts illustrated in this table are the per-participant impacts for customers who received a verification visit from Franklin Energy and an appliance data logger from MadDash.

Source: Guidehouse analysis

In addition to the entire sample of logger water heaters having an average low rate of non-responsiveness, many devices had very low levels of individual non-responsiveness. A histogram of devices segmented by the percentage of events in which they failed to respond to the curtailment signal can be seen in Figure 3-14. The key element of this plot is that the majority of devices were non-responsive only up to 10% of the time, with non-responsiveness above this threshold being uniformly distributed among the remaining water heaters in the logger sample.

Figure 3-14. Percent of Event Days Non-Responsive per Water Heater in Logger Sample



Source: Guidehouse analysis

3.3.3 Implications of Curtailment Responsiveness Findings

Using logger data installed on a subset of appliances that received a verification visit, Guidehouse identified that heat strips continue to have a large degree of non-responsiveness relative to water heaters. To identify whether there were certain heat strips that tended to fail to respond more frequently, Guidehouse illustrated distributions of devices by their percentage of events in which they failed to curtail. These findings suggest that numerous heat strips failed to respond across most events, and another large portion of heat strips often responded to most events. The same finding was not made for water heaters, which consistently responded to most events.

Based on the differences in curtailment responsiveness between the heat strips and water heaters, Guidehouse does not suspect that paging network issues were a primary driver of non-responsiveness. If non-responsiveness were tied to paging network issues, Guidehouse would expect to see similar amounts of non-responsiveness between heat strips and water heaters. Instead, it appears that much of the non-responsiveness that primarily affected heat strips may be driven by equipment malfunctions, despite the logged and investigated equipment having received inspection during verification visits.

Guidehouse recommends that Duke Energy continue to work with Franklin Energy in order to identify the root causes of reduced heat strip responsiveness during DR events. In particular, Guidehouse recommends:

- Visiting sites that previously received a verification visit and received data loggers to inspect equipment functionality, paging signal strength. Guidehouse has provided Duke Energy information surrounding device non-responsiveness for each device that received an appliance logger (e.g., the share of events each device was deemed non-responsive to the signal to curtail) to support this effort.
- Inspecting the ability of switches installed to control heat strips to detect signals pushed from the paging network. Guidehouse observed substantially higher levels of device

responsiveness for water heaters as compared to heat strips, so Guidehouse does not believe there was a paging network outage for certain events in the season. Therefore, Guidehouse recommends that Duke Energy work to determine whether there are differences in how heat strip switches respond to the signal to curtail.

3.4 Comparison of AMI and Logger-Estimated Impacts

Historically, ex-post and ex-ante EWH impacts have been estimated using data collected from data loggers deployed to a representative sample of participating households. For these evaluations, deployment of loggers was costly and substantially limited the size of the EM&V group of participants used to assess program impacts. Therefore, with the availability of AMI across almost all EWH participants, Guidehouse utilized AMI data on a larger set of EM&V participants in the winter 2020/2021 evaluation. However, given lower-than-expected impacts estimated during the 2020/2021 evaluation, in this evaluation Guidehouse includes a comparison of impact results using appliance-level logger data and impact results derived from whole-home AMI data to determine whether reduced impacts could in some way be tied to the use of AMI data.

3.4.1 Comparison of Impacts for Heat Strips and Water Heaters

Guidehouse assessed differences in estimated impacts between logger data and AMI data for participants that received an appliance data logger from MadDash and a verification visit from Duke Energy. To do so, Guidehouse conducted regression modeling on the two parallel data streams, then conducted statistical tests on the difference between quarter-hourly kW estimates derived from logger data and AMI data. Table 3-8 presents a comparison of average water heater curtailment per device using AMI data and logger data. On average across all events, regression models applied to AMI data yielded an impact of 0.25 kW in curtailment per device, while regression models applied to logger data yielded an impact of 0.28 kW in curtailment per device. Guidehouse comparisons of these estimated impacts via a two-tailed t-test identified no significant differences in curtailment between the two data streams.

Table 3-8. Water Heater Curtailment – Comparison of AMI and Logger Estimates

Data Source	Avg. Impact per Device (kW)	Avg. Margin of Error (90% CI)	Relative Precision +/- % (90% Confidence)
Whole-Home AMI Data	0.25	0.07	27%
Appliance-Level Logger Data	0.28	0.06	20%

Note: Per-device impacts illustrated in this table are the per-device impacts for customers who received a data logger from MadDash and a verification visit from Franklin Energy.

Source: Guidehouse analysis.

Table 3-9 presents a comparison of average heat strip curtailment per device using AMI data and logger data for participants that received an appliance data logger from MadDash and a verification visit from Duke Energy. On average across all events, regression models applied to AMI data yielded an impact of 0.36 kW in curtailment per device, while regression models applied to logger data yielded an impact of 0.38 kW in curtailment per device. Guidehouse comparisons of these estimated impacts via a two-tailed t-test identified no significant differences in curtailment between the two data streams.

Table 3-9. Heat Strip Curtailment – Comparison of AMI and Logger Estimates

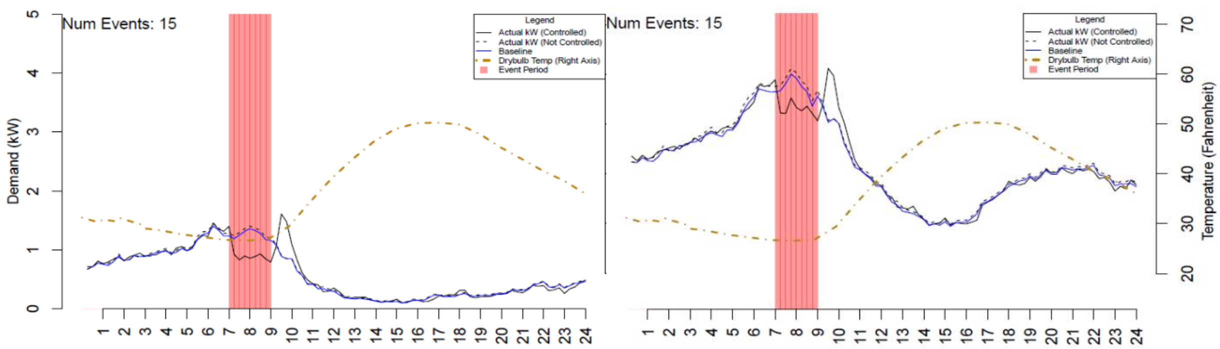
Data Source	Avg. Impact per Device (kW)	Avg. Margin of Error (90% CI)	Relative Precision +/- % (90% Confidence)
Whole-Home AMI Data	0.36	0.06	16%
Appliance-Level Logger Data	0.38	0.06	15%

Note: Per-device impacts illustrated in this table are per-device impacts for customers who received a data logger from MadDash and a verification visit from Franklin Energy.

Source: Guidehouse analysis.

Figure 3-15 presents a side-by-side comparison of heat strip load shapes, with average participant kW on the left-hand plot derived from logger data and average participant kW on the right-hand plot derived from AMI data. As is to be expected, the magnitude of demand is greater when using whole-home AMI data compared to appliance-level logger data. However, the important element of these plots is that the magnitude of curtailment during the DR event, as well as the magnitude of increased demand during snapback period, is roughly equivalent between both data sources.

Figure 3-15. Side-By-Side Comparison of Logger-Based and AMI-Based Load Shapes



Note: Load shapes are presented for participants that received a verification visit from Franklin Energy and an appliance data logger from MadDash.

Source: Guidehouse analysis

3.4.2 Recommendations for this and Future Evaluations

Given the relative equivalency between logger-based and AMI-based impact estimates, Guidehouse believes that the switch from logger-based impact reporting to AMI-based reporting is not the cause of the lower-than-expected impacts estimated in the previous evaluation. To inform recommendations surrounding this evaluation and future evaluations, Guidehouse provides advantages of using AMI and logger data (previously provided in the summer 2019 evaluation of EWH) in Table 3-10 below.

Table 3-10. AMI vs. Logger Data by Characteristic

Characteristic	AMI Data	Logger Data	Advantage
Observed Value	AMI meters measure true power on a quarter-hourly basis.	Data loggers[21] measure amperage not true power.[22] Power values are estimates obtained by applying observed amps to spot-measurements of device power factor.	**AMI Data.** True power is observed, vs. estimated.
Appliance Demand	AMI data measure whole-house demand. The demand of the controlled appliance cannot be observed in isolation.	Each logger provides an appliance-specific time series of demand. This enables analyses such as identifying non-response or partial response for connected devices. This can be helpful to program staff as the program develops to better understand and observe technical issues associated with load switches.	**Logger Data.** With AMI data the appliance demand can only be estimated (disaggregated) not observed.
Program Impacts	AMI data measure whole-home demand, which is the combined effect of curtailment (demand reductions) as well as any indirect effects (e.g., additional use of space heating to maintain preferred indoor temperature).	A logger data analysis considers only the appliance demand. There is a risk here that estimated impacts may not capture interactions between the appliance curtailed, and other equipment/behaviors.	**AMI Data.** If there are secondary effects impacting DR, the analysis should account for these.
Deployment and Data Collection	Data are collected automatically on an ongoing basis, and so are available at relatively low cost. Careful sampling is required, including over-sampling in some strata, as the sample of AMI-equipped participants may not be representative of the overall participant population (those with and without AMI data).	Logger deployment is very expensive. Field work is typically the single highest cost of a logger-enabled evaluation. Logger deployment (dedicated customer visits) is helpful, however, in identifying participant connectivity and operability (i.e., what portion of the population's load switch remains connected).	**AMI Data.** Though the information gathered by site visits is useful in understanding impacts, it is not sufficiently valuable to offset logger deployment costs.

Source: Guidehouse

To summarize, the advantage in using AMI data to estimate impacts is that:

- AMI data provides measured true power instead of an estimate of true power via logged amps and spot measurements of voltage and power factor.
- AMI data includes all loads in the home. All possible impacts are therefore taken into account in the analysis, whereas the logger data only provides estimated impacts from the primary controlled load, ignoring possible secondary effects of the event elsewhere in the home (e.g., increased use of space heating equipment during events).
- AMI data are much less costly to collect than logger data, though site visits for logger install can also yield useful information beyond just the logger data (e.g., equipment tampering).

[21] Of the type historically deployed for the evaluation of this and other demand response programs.

[22] True power logging is more expensive and involved, so many DR evaluations utilize current transducer (CT) loggers coupled with power factor and voltage measurements. Since power factor spot measurements are only taken during logger deployment and collection, and power factor is a function of the appliance load, spot measurements may understate demand (and potentially) impacts on very cold days.

Given that AMI data measure true power and capture any potential secondary or offsetting effects (e.g., increased usage of space heating) during events, Guidehouse believes that the prudent approach for this year's evaluation is to treat the AMI data-estimated impacts as the best available estimates of demand response impacts on a per-participant basis. Given this finding along with the cost of deploying data loggers to an EM&V sample and the increasing availability to participant AMI data, Guidehouse recommends that future evaluations of the EWH program be conducted with AMI data obtained from an EM&V sample of program participants. However, Guidehouse does recommend occasionally (e.g., once every 4 years) installing loggers at a small sample of sites for the purposes of assessing technical issues associated with load switches and controlled equipment.

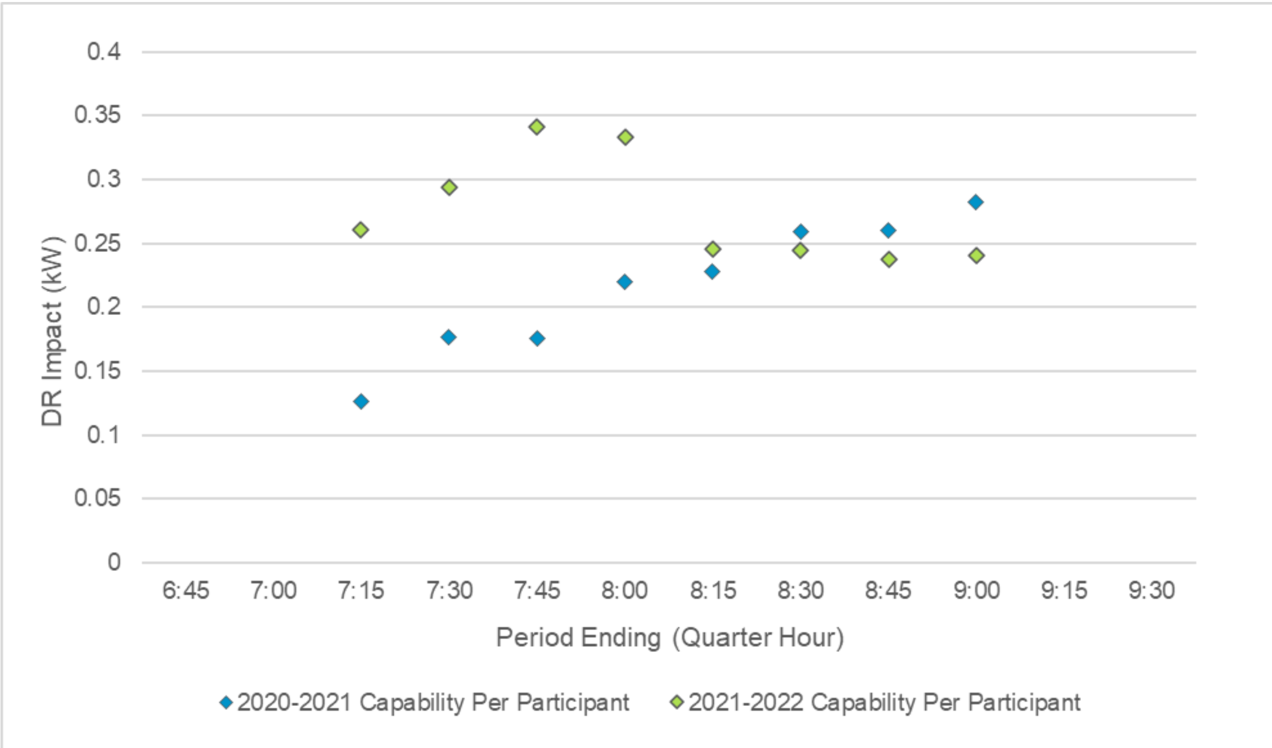
3.5 Comparison of Winter 2021/2022 and Winter 2020/2021 Evaluation Results

This section summarizes differences in evaluation results between winter 2020/2021 (Guidehouse's prior evaluation period) and winter 2021/2022 (the current evaluation period). Estimated impacts from the winter 2020/2021 evaluation yielded significantly lower estimated impacts and projected capability than those provided in the winter 2017/2018 report. The primary theory offered for these results was that a significant portion of appliances failed to respond to curtailment signals. However, due to the lack of appliance-level logger data, this could not be tested conclusively. As noted in the prior report, the Duke Energy DR paging system is only capable of one-way communication, so it is only possible to assess individual appliance responsiveness via direct observation of appliance load profiles. Therefore, in the lead up to the winter 2021/2022 season, Guidehouse recommended that Duke Energy work with a contractor to verify the functionality of all EM&V participants' devices, and to remediate when necessary. Once verification visits commenced, MadDash installed appliance-level loggers in the homes of a subset of participants that received a verification visit from Franklin Energy.

3.5.1 Comparison of Water Heater Results

Figure 3-16 provides a comparison of average kW reductions estimated for each quarter-hour of events in winter 2020/2021 and winter 2021/2022. Estimates for winter 2021/2022 are slightly greater than the estimates from winter 2020/2021, particularly during the first hour of events. Greater estimated kW reductions during the first hour of events in winter 2021/2022 may be driven by increased usage of hot water, and therefore greater curtailment capability, during the earlier morning hours compared to winter 2020/2021. However, given Guidehouse does not have appliance logger data to compare between the two evaluation years, Guidehouse cannot confirm whether water heater demand was greater during this evaluation period.

Figure 3-16: Comparison of Water Heater Capability



Note: Winter 2021/2022 capability estimates are presented for participants that received a verification visit from Franklin Energy.
Source: Guidehouse analysis

Table 3-17, below, provides the average estimated ex-post impact of water heater impacts from the two most-recent evaluation cycles. These events started as early as 6 AM and ended as late as 10 AM, though the vast majority took place no earlier than 6:30 AM and no later than 9:00 AM. Notably, the estimated per-device impacts have increased since winter 2020/2021. Based on the comparison of quarter-hourly impact estimates above, the increase in impacts in winter 2021/2022 is attributed to the increased curtailment observed during the first hour of events relative to winter 2020/2021.

Table 3-17: Comparison of Average Ex-Post Water Heater Impacts from Prior Evaluations

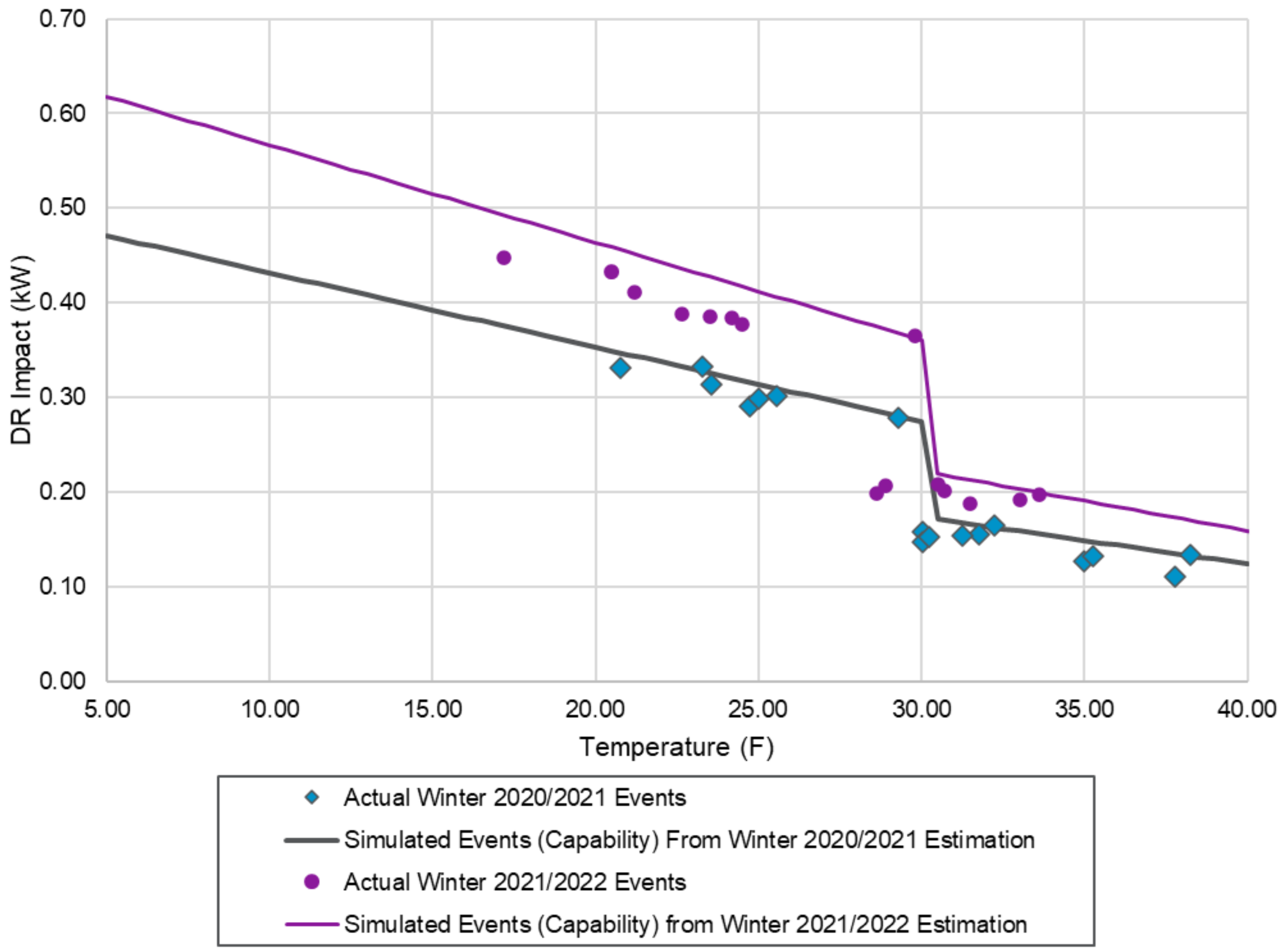
Evaluation Year	Estimated Average Impact Per Water Heater (kW)
2020/2021	0.21
2021/2022	*0.27*

Note: Winter 2021/2022 average estimated impact per water heater is presented for participants that received a verification visit from Franklin Energy.
Source: Guidehouse analysis

3.5.2 Comparison of Heat Strip Results

Figure 3-18 below compares the average per-participant projected capability with curtailable heat strips from 5°F to 50°F for winter 2020/2021 (blue line) and winter 2021/2022 (purple line). Actual estimated EM&V event impacts are also represented on this chart for winter 2020/2021 (in blue diamonds) and winter 2021/2022 (in purple dots).This capability was projected by applying a series of temperature values to the estimated model parameters and assumes that the temperature at which the capability is estimated lasts the entire length of the event and is the same as the temperature in the three hours leading up to the event.[23] Although slightly higher than the estimates reported last year, the average estimated program capability continues to be lower than expected.

Figure 3-18: Comparison of Heat Strip Capability



Note: Winter 2021/2022 capability estimates are presented for participants that received a verification visit from Franklin Energy.
Source: Guidehouse analysis

Estimates of projected per-participant load shed are subject to several factors; most notably, temperature, device usage at the time of an event, and device non-responsiveness to curtailment signals. Combined, these factors have created significant variability in impacts between evaluation years.

[23] This assumption is required due to the way impacts are estimated. Heat strip DR impacts were modeled, in part, as a function of the exponential moving average of heating degree quarter-hours. As such, Guidehouse's projected capability assumes that the temperature at which the capability is estimated lasts the entire length of the event and is the same as the temperature in the three hours leading up to the event.

As identified in Section 3.3, there was evidence of device non-responsiveness amongst the heat strips that received a verification visit. In addition, Guidehouse identified that many controlled devices were not in use at the time of events. Both factors are likely to be key contributors to the continuing lower-than-expected per-device impacts estimated for called demand response events. For instance, devices not in use during the time of an event will cut into the overall curtailment capability, as the amount of curtailable load at the time of an event has a direct impact on the amount of load curtailment able to be realized. Device non-responsiveness to curtailment signals further cuts into the amount of curtailable load.

Despite our ability to identify non-responsive and non-participating devices in winter 2021/2022 events, the winter 2020/2021 evaluation did not utilize data from appliance loggers, and therefore Guidehouse cannot provide a comparison of device non-responsiveness between the two evaluations. Regardless, in Table 3-11 Guidehouse summarizes overall device non-responsiveness and device not-in-use rates estimated during winter 2021/2022 events.

Table 3-11: Summary of Heat Strip Non-Responsiveness and Not-in-Use Rates During Events

Metric	Average	Max	Min	# of Heat Strips with Loggers	# of Events
Percentage of Devices Non-Responsive During Events*	57%	83%	35%	77	14
Percentage of Devices Not in Use During Events	41%	62%	27%	77	14

*Note: Estimates provided in this table are for participants that received appliance data loggers from MadDash and a site verification visit from Franklin Energy. The percentage of devices non-responsive during events excludes devices that were not in use during the time of events. As such, percentages included in Section 3.3 do not directly correspond to percentages presented in this table.

Source: Guidehouse analysis

As summarized above, device non-responsiveness varied from 35 percent to 83 percent of devices per event. A cause for fluctuation in device non-responsiveness was not able to be identified, as there was not a clear relationship between non-responsiveness and temperature or other conditions observable to Guidehouse. Device not-in-use rates also varied across events, with a large share of devices not in use at the time of events called in winter 2021/2022. Based on comparisons of heat strip responsiveness across events, summarized in Section 3.3.1, many heat strips were not in use during warmer events called throughout the season. Higher temperatures observed in winter 2021/2022 relative to prior evaluation periods may therefore explain a portion of underperformance.

3.5.3 Potential Causes of Reduced Impacts

The substantially reduced per-participant and per-device impacts estimated for 2021/2022 compared to previous years is a matter of concern to Guidehouse and to Duke Energy. Guidehouse carefully reviewed the data for this DR season as well as from prior evaluations and believes a major contributor to reduced impacts are rates of device non-responsiveness and devices not in use at the time of an event, particularly for heat strips. However, uncertainty surrounding the cause of lower impacts remains, with insufficient evidence available to conclusively identify an additional cause or causes.

Similar to what was presented in the winter 2020/2021 evaluation, the table immediately below provides a summary of the hypotheses considered by Guidehouse, the evidence for or against them, and Guidehouse's conclusion regarding the likelihood of that hypothesis.

Table 3-12: Potential Causes of Reduced Impacts

#	Hypothesis	Context	Evidence	Conclusion
1	Logger measurement error.	If logger reads were inaccurately inflated, transition to AMI data would result in much lower impacts.	Side-by-side comparison of logger and AMI-estimated impacts in this evaluation found the estimated difference between AMI and logger-derived impacts to not be statistically significant.	Hypothesis rejected.
2	Heat strip energy consumption has declined over time.	If heat strip energy consumption has fallen across households enrolled in the EWH program in winter 2021/2022 relative to what was observed in prior evaluations, then curtailment capability will be reduced.	Guidehouse separately assessed likeness of appliance-specific logger kW from enrolled heat strips between winter 2017/2018 and winter 2021/2022. In this comparison, Guidehouse identified reduced heat strip demand across every temperature in winter 2021/2022 relative to winter 2017/2018.	Hypothesis cannot be rejected at this time. Guidehouse believes that a portion of reduced impacts may be explained by an overall reduction in observed heat strip consumption across every temperature. However, this is not a sole contributor to reduced impacts, as Guidehouse has illustrated a significant portion of heat strips were non-responsive during DR events.

#	Hypothesis	Context	Evidence	Conclusion
3	Whole-home consumption captures secondary effects that “take back” DR not captured in prior logger studies.	If some secondary appliance serves the same end-use as the controlled load, it is possible that load from secondary appliance could increase during events (in response to reduced output from controlled equipment), offsetting DR impacts.	*Water Heaters:* for most homes storage water heaters are the only source of domestic hot water for showering (key driver of water heater impacts). *Heat Strips:* incremental secondary space heater (e.g., baseboard) loads in response to heat strip curtailment would reduce whole home DR impacts but leave appliance-specific (data logger-connected) loads unaffected. Take-back from thermostatically controlled secondary heaters is possible only if set-point is higher than minimum indoor temperature during event *and* room in which heating is located is also served by controlled heat pump. Take-back from manually controlled secondary heaters is possible only if participant notices heat pump curtailment and responds by turning on the secondary heater.	*Water Heaters:* Hypothesis rejected. *Heat Strips:* Hypothesis rejected. Guidehouse believes that the sequence of events required to result in DR take-back from secondary space heaters is not a driver of reduced estimated impacts. This is based on side-by-side logger data/AMI data analysis, which indicate no significant differences in assessed impacts between the two data sources.
4	COVID-related behavior change	Guidehouse has noted in some other evaluations that public health restrictions in response to COVID led to a “stretching” of the morning peak, suggesting a shifting of early morning pre-work behavior to later in the day. Participants choosing to shower later in the day (i.e., outside of the DR event period) would lower DR impacts compared to in previous years.	In the winter 2020/2021 evaluation, Guidehouse compared the normalized load profile of water heater only participants on non-event days in the 2021 DR season with a normalized load profile for the same participants drawn from January and December of 2020. This comparison showed a difference between the load profiles that is consistent with the hypothesis of shifted showering behavior.	Hypothesis cannot be rejected at this time. The observed difference in load profiles shown in the winter 2020/2021 evaluation is highly suggestive of the hypothesized change in behavior. It is unclear, however, how much of the magnitude in reduced water heater DR capability can be attributed to this apparent change in participant behavior.

#	Hypothesis	Context	Evidence	Conclusion
5	Heat strip switch functionality has declined.	This hypothesis was developed as a result of the results of winter 2020/2021 Duke Energy field verification of a sample of 46 heat strip participants' homes.	As discussed in the winter 2020/2021 evaluation for the EWH program, Duke Energy staff conducting field verification of EM&V participant homes found that an extremely high proportion of switches in these homes were effectively non-functional (for a variety of reasons). For example, nearly half of switches had been disconnected by the customers themselves.	Hypothesis cannot be rejected at this time. Evaluation results for winter 2021/2022 are based on a sample of EM&V participants that received field verifications from Franklin Energy. Despite having received field verifications, Guidehouse identified a significant number of heat strips were not responding to the signal to curtail. As such, Guidehouse recommends that Duke Energy continue to work with its Franklin Energy to determine a cause for heat strip non-responsiveness during events, even for sites that received a field verification visit.
6	Paging network outages may have caused devices to fail to curtail during events called in winter 2021/2022.	In the winter 2020/2021 evaluation, Guidehouse identified several paging towers were offline for a significant portion of the DR events called. This may have been a contributor to reduced impacts in that evaluation period.	Heat strips were not responding to the signal to curtail for an average of 33% of devices at the time of an event. Further, based in investigations provided in Appendix C. Comparison of Curtailment by ZIP Code, curtailment outcomes appear to be, in-part, location specific, with better curtailment outcomes for heat strips installed at facilities near the Lyn Lowery paging tower. This may indicate that paging tower issues persisted into this evaluation period for several locations in DEP's Western region.	Hypothesis rejected. Investigation of logger data for sites with controlled heat strips revealed that several sites consistently did not respond to the signal to curtail. However, investigation of logger data for sites with controlled water heaters indicate that around 10% of devices were non-responsive at the time of an event, with 70% at least partially responsive at the time of an event. If paging network issues persisted into winter 2021/2022, Guidehouse would have expected to see similar rates of non-responsiveness between water heaters and heat strips. As such, Guidehouse does not believe paging network issues are the primary cause of reduced impacts.

Source: Guidehouse

Guidehouse recommends that Duke Energy continue to work with Franklin Energy in order to identify additional root causes of reduced heat strip and water heater curtailment during DR events. In particular, Guidehouse recommends:

- Visiting sites that previously received a verification visit and data loggers to inspect equipment functionality, paging signal strength. Guidehouse has provided information surrounding device non-responsiveness for each device that received an appliance logger (e.g., the share of events each device was deemed non-responsive to the signal to curtail) to support this effort.
- Inspect ability of switches installed to control heat strips to detect signals pushed from the paging network. Guidehouse observed substantially higher levels of device responsiveness for water heaters as compared to heat strips, so Guidehouse does not believe there was a paging network outage for certain events in the season. Guidehouse recommends that Duke Energy work to determine whether there are differences in how heat strip switches respond to the signal to curtail.

3.6 Net-to-Gross

Evaluations of demand-side management programs typically estimate a net-to-gross (NTG) ratio based on the evaluated percentage of demand reductions that may be ascribed either to free ridership (which decreases the NTG ratio) or to program spillover (which increases it). Free ridership is typically defined as the percentage of demand reductions that would have occurred anyway, absent the presence of the program. Spillover is typically defined as incremental demand reductions undertaken by nonparticipants or extra reductions taken by participants that were not directly incented by the program administrator but caused by the program. In the analysis in this report, because demand reductions are estimated in contrast to an implied estimated baseline[24] that captures expected behavior absent an event, Guidehouse can confidently state that the free ridership is 0: absent the EWH program, none of the estimated demand reductions would have taken place. It is possible that there may have been some spillover resulting from the program (from participants becoming more aware of their sites' consumption profiles, for example). However, it is likely impossible to estimate such an effect in a sufficiently robust manner and the assessment of such impacts is beyond the scope of this report.

Since spillover cannot be robustly estimated and because free ridership must, by program design, be considered 0, Guidehouse considers the EWH program to have a NTG ratio of 1.

[24] That is, the average level of behavior implied by the estimated parameter values of the regressions used.

4. Findings, Conclusions, and Recommendations

4.1 Findings and Conclusions

The principal EM&V impact findings and conclusions regarding the winter event demand impacts for 2021/2022 are as follows:

- **Average estimated impacts and projected capability are higher than estimated in the winter 2020/2021 evaluation.** During EM&V events, Guidehouse estimated average demand reductions of 0.31 kW per heat strip participant and 0.27 kW per water heater participant. These estimates are 0.10 kW and 0.05 kW higher, respectively, than those of the 2020/2021 evaluation. During population events, Guidehouse estimated average demand reductions of 0.34 kW per heat strip participant and 0.37 kW per water heater participant. Guidehouse's projected capability of savings are 0.57 kW per heat strip and 0.29 kW per water heater. In comparison to the winter 2020/2021 evaluation estimates, projected capability has increased by 0.14 kW per heat strip participant and 0.03 kW per water heater participant.
- **The estimated average impact of the winter 2021/2022 EM&V water heater events was 0.27 kW per participant.** This represents the average of the estimated impacts across 24 water heater events taking place between 7:00 and 9:00 in the morning. This average per participant impact is higher than the 0.21 kW per participant that was estimated in winter 2020/2021
- **The estimated average impact of heat strips over the four coldest events during the winter 2021/2022 season was 0.42 kW per participant and 0.39 kW per appliance.** The average temperature across these events was approximately 20°F, with a minimum observed temperature of 17°F.
- **The current DR capability of DEP's EnergyWise program in the winter is approximately 0.64 MW**. Note that this estimate includes only the households that received a verification visit and is the summation of the projected capability of 0.37 MW from heat strip curtailment when the average temperature is 10°F (0.53 kW per appliance) and 0.28 MW from water heater curtailment deployed between 7:30 and 8:30 in the morning (0.29 kW per appliance).
- **There is no statistically significant difference in impact estimates derived from AMI-based data or logger-based data**. One of the principal motivations for reincorporating logger data into this year's evaluation was to confirm the robustness of evaluating DEP EWH impacts from whole-home AMI data and to rule out the theory that the change from appliance-based logger data to whole-home AMI data was responsible for the decrease in savings estimated between the 2017/2018 and 2020/2021 evaluations. Guidehouse confirmed that whole-home AMI data is a valid source of data in determining the impacts of DR events on appliance-level demand and that the magnitude of estimated impacts is comparable between both data sources.

4.2 Recommendations

The principal EM&V recommendations regarding the winter event demand impacts for 2021/2022 are as follows:

- **Continue to use AMI data in future evaluations of the EWH program.** Based on comparisons of logger-based and AMI-based impact estimates, Guidehouse identified no differences in assessed impacts between the two parallel data streams. Guidehouse believes that a switch from logger-based impact reporting to AMI-based reporting is not the cause of the lower-than-expected impacts estimated in this evaluation. Combined with AMI data's ability to capture whole-home load and secondary increases in consumption across other end-uses (e.g., increased use of space heating equipment) and its substantially lower cost compared to logger data, Guidehouse recommends continued use of AMI data in order to inform program impact estimates.
- **Continue to work with Franklin Energy to identify and remediate causes of reduced impacts.** Investigation of appliance logger data collected from a subset of sites that received a verification visit revealed continued non-responsiveness of heat strips, despite these devices having received a verification visit. Guidehouse recommends that Duke Energy continue to work with Franklin Energy to visit sites that previously received a verification visit to inspect equipment functionality.

5. Summary Form

Duke EnergyWise Home
2021-2022
Completed EMV Fact Sheet

Description of Program

The EnergyWise Home (EWH) demand response (DR) program offers Duke Energy Progress (DEP) residential customers the opportunity to earn credits on their electricity bill by allowing DEP to remotely cycle and curtail air conditioners (A/C) during times of peak seasonal load in the summer months (available system wide) and space- and water-heating equipment in winter months (available for western region customers only).

This report evaluates the impact of the program in the winter of 2021/2022. Four program-wide heat strip events and one program-wide water heater event was called in the winter of 2021/2022, in addition to 15 heat strip EM&V events and 24 water heater EM&V events. Guidehouse estimated savings impacts for a subset of EWH customers who had received a visit from Franklin Energy to verify the working order of their devices.

Date:	2023-02-01
Region:	Duke Energy Progress
Evaluation Period	Winter 2021/2022
DR Event Capability (kW) per Customer	
Heat Strip	0.57
Water Heater	0.29
Total DR Event Capability (MW)	
Heat Strip	0.37
Water Heater	0.28
Ex-Post EM&V Event Impacts (kW) per Customer	
Heat Strip	0.31
Water Heater	0.27
Total Ex-Post EM&V Event Impacts (MW)	
Heat Strip	0.20
Water Heater	0.26

Impact Evaluation Methods

Guidehouse used an econometric technique known as a fixed effects regression to estimate the impacts of the devices curtailed. Fixed effects regression is a form of linear regression commonly used to estimate the impact of DR programs. For this evaluation, the technique is applied to a set of observations of some variable of interest from several different individuals in order to control for time-invariant determinants of electrical demand.

In order to create a randomized control trial, Guidehouse randomly allocated each EM&V participant site to one of two groups: Group A or Group B (for customers with controlled heat strips) or Group C or Group D (for customers with controlled water heaters). Under this design, when one group (e.g., Group A) is subject to curtailment (for a given event), the other (e.g., Group B) is not, with the group curtailed changing from event to event.

Impact Evaluation Details

- Average estimated impacts and projected capability are higher than estimated in the winter 2021/2022 evaluation. During EM&V events, each heat strip participant saw a demand reduction of 0.31 kW and each water heater participant saw a demand reduction of 0.27 kW. Compared to the results of the winter 2020/2021 evaluation, these estimates represent an increase of 0.10 kW and 0.05 kW, respectively. During population events, Guidehouse estimated average demand reductions of 0.34 kW per heat strip participant and 0.37 kW per water heater participant. Guidehouse's projected capability of savings are 0.57 kW per heat strip and 0.29 kW per water heater. In comparison to the winter 2020/2021 evaluation estimates, projected capability has increased by 0.14 kW per heat strip participant and 0.03 kW per water heater participant.
- The estimated average impact of the winter 2021/2022 EM&V water heater events was 0.27 kW per participant. This represents the average of the estimated impacts across 24 water heater events taking place between 7:00 and 9:00 in the morning. This average per participant impact is higher than what was estimated in winter 2020/2021, but is less than what was estimated in prior evaluations spanning winter 2011/2012, winter 2014/2015, and winter 2017/2018.
- The estimated average impact of heat strips over the four coldest events during the winter 2021/2022 season was 0.42 kW per participant and 0.39 kW per appliance. The average temperature across these events was approximately 20°F, with a minimum observed temperature of 17°F.
- The current DR capability of DEP's EnergyWise program in the winter is approximately 0.64 MW. Note that this estimate includes only the households that received a verification visit and is the summation of the projected capability of 0.37 MW from heat strip curtailment when the average temperature is 10°F (0.53 kW per appliance) and 0.28 MW from water heater curtailment deployed between 7:30 and 8:30 in the morning (0.29 kW per appliance).

A. Regression Model Specification

This appendix provides more detail on the methods employed by the evaluation team to estimate DR impacts and the capability of heat strips and water heaters controlled during the winter of 2021/2022. It is divided into three sections. The first addresses water heater estimates generated using AMI data, the second addresses water heater estimates generated using logger data, and the third addresses heat strip estimates generated using both AMI and logger data.

A.1 Water Heater Model Specification and Details – AMI Data

AMI-based water heater impacts were estimated using a single regression equation, shown in Equation A-1, below. Only event days were included in the estimation set. Limiting the estimation set to include event days only is possible due to the two-group RCT-style experimental design.

Note that the specification below is considerably more complex than used in prior years when logger data were available. The logger data used in previous years provide appliance-specific demand values. The regression specification therefore needs only capture the expected baseline behavior of the water heater. For this evaluation, whole home AMI data are used. This means that additional variables need to be included to control for the effects of (for example) weather on whole-home demand, even though intra-daily weather has no real impact (per prior years' analysis) on water heater demand.

Equation A-1: Water Heater Regression Equation – AMI Data

$$
\begin{aligned}
y_{i,t} = {} & \sum_{r=1}^{R=2} \alpha_{i,r} * spline_{r,t} + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{1,q} * qh_{q,t} * cbu_{i,t} + spline_{r,t} + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{2,q} * qh_{q,t} * cbu_{i,t} * spline_{r,t} * visited_{i,t} \\
& + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{3,q} * qh_{q,t} * emaHDQH_{i,t} * spline_{r,t} \\
& + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{4,q} * qh_{q,t} * emaHDQH_{i,t} * spline_{r,t} * visited_{i,t} + \sum_{r=1}^{R=2} \sum_{d=1}^{D=8} \gamma_{d,1} * relQH_{i,t} * c_{i,t} \\
& + \sum_{r=1}^{R=2} \sum_{d=1}^{D=8} \gamma_{d,2} * relQH_{i,t} * c_{i,t} * visited_{i,t} + \sum_{r=1}^{R=2} \sum_{s=1}^{S=15} \beta_{5,s} * sb_{i,t,s} * numQH_{i,t} \\
& + \sum_{r=1}^{R=2} \sum_{s=1}^{S=15} \beta_{6,s} * sb_{i,t,s} * numQH_{i,t} * visited_{i,t}
\end{aligned}
$$

Where:

$y_{i,t}$ = Water heater participant *i*'s demand during quarter-hour of sample *t*.

$spline_{r,t}$ = A set of two dummy variables.

One is equal to 1 when the value of $emaHDQH_t$ is less than 35 (approximately equivalent to taking a value of one when the temperature is greater than 30°F).

The other is equal to 1 when the value of $emaHDQH_t$ is greater than or equal to 35 (approximately equivalent to taking a value of one when the temperature is less than or equal to 30°F). This hinge point temperature was selected on the basis of analysis included in Appendix A of the 2017/2018 EnergyWise Home evaluation that found that the relationship between heat strip demand and temperature changed materially on either side of this hinge point.[25]

α_i = An individual participant-level fixed effect. This is equivalent to a battery of dummy variables, one for each participant. This set of dummy variables controls for all time-invariant differences in demand between participants (e.g., the size of the home, etc.)

$qh_{q,t}$ = Dummy variables (96) to capture time of day effects. Each one is equal to 1 when quarter-hour of sample *t* is the *q*-th quarter-hour of that day, and 0 otherwise.

cbu_t = Cold buildup observed in quarter-hour of sample *t*. This is a 72-hour geometrically decaying average of the NOAA-defined wind chill/temperature index.[26] It is calculated in the following manner:

$$cbu_t = \sum_{h=1}^{72} 0.96^h \cdot wchill_{t-h} \Big/ 1{,}000 \ .$$

Note in this case that the *t* subscript denotes hourly intervals. As noted above, the cbu_t (normalized cold buildup) is a geometrically decaying 72-hour moving average of NOAA's wind chill/temperature index. That variable is calculated in the following manner:

$$wchill_t = 35.74 + 0.6215 \cdot drybulb_t - 35.75 \cdot (0.16 \cdot ws_t) + 0.4275 \cdot drybulb_t \cdot (0.16 \cdot ws_t)$$

Where $drybulb_t$ is the drybulb temperature (in °F) observed at quarter-hour *t* and ws_t is the windspeed in miles per hour observed at quarter-hour *t.*

[25] The inclusion of this term is predicated on the fact that at least some water heater participants also use heat pumps (with auxiliary heat strips) for space-heating and that the improved precision the inclusion of these terms offers outweighs the reduction in precision imposed by the loss of degrees of freedom associated with including additional independent variables.

[26] NOAA, National Weather Service, *Wind Chill/Temperature Index*, accessed August 2019. **https://www.weather.gov/oun/safety-winter-windchill**

$emaHDQH_t$	=	A 3-hour exponential moving average of heating degree quarter-hours (HDQHs). That is, an exponential moving average that includes the current quarter-hour *t* and the 11 quarter-hours prior to that. The moving average calculated over HDQHs with a base of 65°F (i.e., HDQH is equal to 65 minus temperature, or 0, whichever is highest).
$relQH_{d,t}$	=	A set of 8 dummy variables, each equal to 1 when quarter-hour *t* is the *d*-th quarter-hour of the event. Note that although this differs somewhat from the approach used in prior years – in which the treatment or curtailment dummy was interacted with the absolute as opposed to the relative quarter hour of the day – the practical effect is the same as all events start at the same time of day and last the same number of hours. For example, relative quarter hour 1 is always the period between 7:00 and 7:15 AM.
$c_{i,t}$	=	A dummy variable equal to 1 when participant *i* is expected to curtail (i.e., is in Group A during a Group A curtailment event or is in Group B during a Group B curtailment event).
$sb_{i,t,s}$	=	A set of 15 dummy variables. Each one is equal to 1 when quarter-hour *t* is the *s*-th quarter-hour following the end of a DR event and when participant *i* was expected to be curtailed on event day *t*.
$numQH_{i,t}$	=	The number of quarter hours that the DR event to which participant *i* was subject, that took place on day *t* lasted, and 0 otherwise.
$visited_{i,t}$	=	A dummy variable equal to 1 if participant *i* has received a verification visit by quarter-hour of sample *t,* and 0 otherwise

A.2 Water Heater Model Specification and Details – Logger Data

Logger-based water heater impacts were estimated using a single regression equation, shown in Equation A-2, below. Only event days were included in the estimation set. Limiting the estimation set to include event days only is possible due to the two-group RCT-style experimental design. Note that the specification below is comparable to the specification used in prior years when logger data were available. The logger data provide appliance-specific demand values, and therefore the model needs only capture the expected baseline behavior of the water heater rather than the whole home. As such, additional variables that were needed to control for the effects of (for example) weather on whole-home demand do not need to be included in the regression model.

Equation A-2: Water Heater Regression Equation – Logger Data

$$y_{i,t} = \alpha_i + \sum_{q=1}^{Q=96} \beta_{1,q} * qh_{q,t} + \sum_{q=1}^{Q=96} \beta_{1,q} * qh_{q,t} * ma2wkHDQH_{i,t} + \sum_{q=36}^{Q=43} \gamma_{q,1} * c_{i,t} * qh_{q,t} + \sum_{s=1}^{S=15} \beta_{4,s} * numQH_{it} * sb_{i,t,s} + \epsilon_{i,t}$$

Where:

$ma2wkHDQH_{i,t}$	=	The two-week moving average of HDQHs to which participant *i*

was exposed over the course of the two weeks prior to the event that took place on day *t*, and 0 otherwise.

And all other variables are as defined above.

A.3 Heat Strip Model Specification

Heat strip impacts were estimated using a single regression equation, shown in Equation A-3, below. Only event days were included in the estimation set. Limiting the estimation set to include event days only is possible due to the two-group RCT-style experimental design.

Equation A-3: Heat Strip Regression Equation

$$
\begin{aligned}
y_{i,t} = {} & \sum_{r=1}^{R=2} \alpha_{i,r} * spline_{r,t} + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{1,q} * qh_{q,t} * spline_{r,t} + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{2,q} * qh_{q,t} * spline_{r,t} * visited_{i,t} \\
& + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{3,q} * qh_{q,t} * emaHDQH_{i,t} * spline_{r,t} \\
& + \sum_{r=1}^{R=2} \sum_{q=1}^{Q=96} \beta_{4,q} * qh_{q,t} * emaHDQH_{i,t} * spline_{r,t} * visited_{i,t} \\
& + \sum_{r=1}^{R=2} \sum_{d=1}^{D=16} \gamma_{d,1} * relQH_{i,t} * c_{i,t} * emaHDQH_{i,t} * spline_{r,t} \\
& + \sum_{r=1}^{R=2} \sum_{d=1}^{D=16} \gamma_{d,2} * relQH_{i,t} * c_{i,t} * emaHDQH_{i,t} * spline_{r,t} * visited_{i,t} \\
& + \sum_{r=1}^{R=2} \sum_{s=1}^{S=15} \beta_{5,s} * sb_{i,t,s} * eventHDQH_{i,t} * spline_{r,t} \\
& + \sum_{r=1}^{R=2} \sum_{s=1}^{S=15} \beta_{6,s} * sb_{i,t,s} * eventHDQH_{i,t} * spline_{r,t} * visited_{i,t}
\end{aligned}
$$

Where:

$eventHDQH_{i,t}$ = The sum of HDQHs to which participant *i* was exposed over the course of the event that took place on day *t*, and 0 otherwise.

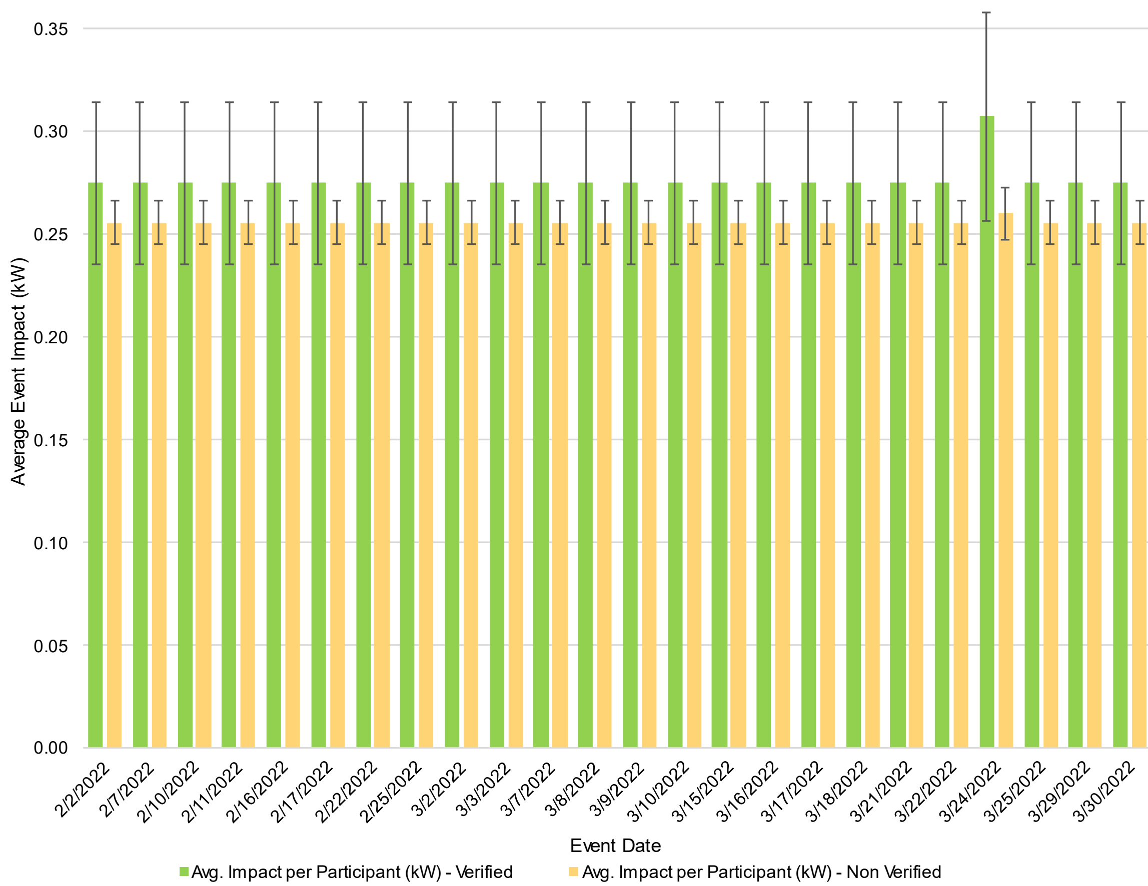
And all other variables are as defined above.

B. Comparison of Results Verified vs. Non-Verified Sites

B.1 Comparison of Verified and Non-Verified Water Heater Impacts

To provide additional context for the impact results presented in the main body of this report, Guidehouse has also estimated the water heater savings impact for sites that did not receive a visit from Franklin Energy (i.e., non-verified sites). Figure B-1 provides a graphical summary of the estimated DR impact of water heater curtailment for 24 EM&V events called in the winter of 2021/2022. Each vertical bar represents the average estimated event impact for sites that received a verification visit (in green) and for sites that did not receive a verification visit (in yellow). The 90% confidence interval is identified by the whiskers.

Figure B-1. Water Heater Event Impacts – Verified & Non-Verified Sites



Source: Guidehouse analysis

Differences in curtailment between sites that received a verification visit and those that did not receive a verification visit were minimal in winter 2021/2022; observed curtailment for sites that received a verification visit was 0.27 kW per participant, while curtailment for sites that did not receive a verification visit was 0.26 kW per participant. Guidehouse did not identify statistically significant differences in impacts between verified and non-verified participants.

The same information presented in the figure above can be seen in the table below.

Table B-1. Water Heater Event Impacts – Verified & Non-Verified Sites

Participant Group	Avg. Impact per Participant (kW)	Avg. Margin of Error (90% CI)	Relative Precision +/- % (90% Confidence)
Verified Sites	0.27	0.04	14%
Non-Verified Sites	0.26	0.01	4%

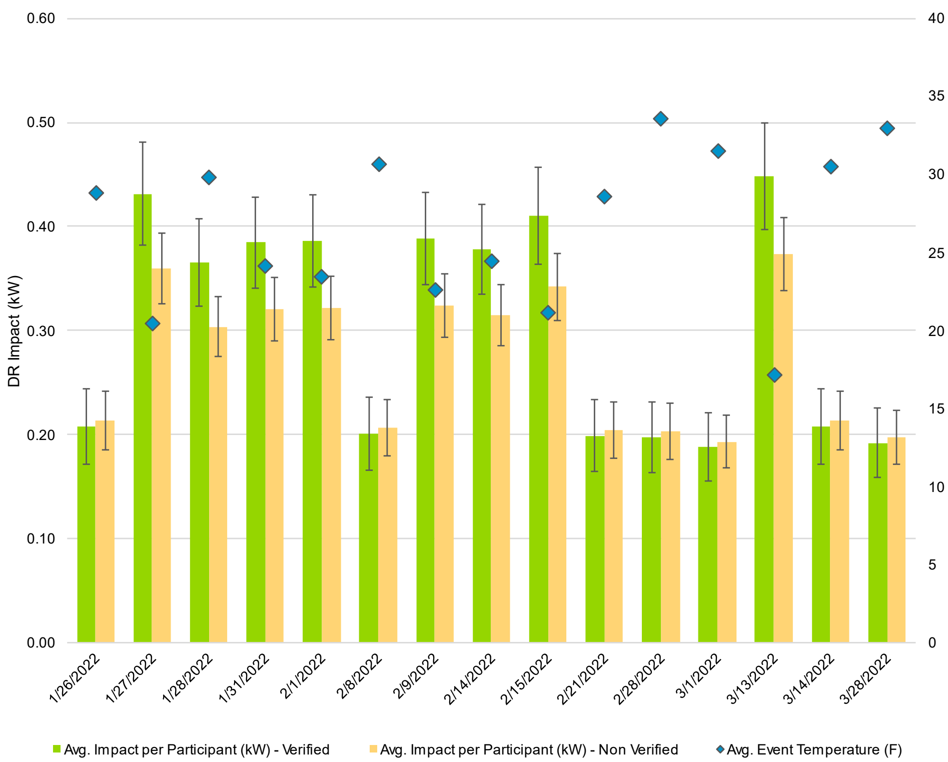
Average impact per participant, average margin of error, and average relative precision are calculated by taking the average of each of the three metrics across all events called.

Source: Guidehouse analysis

B.2 Comparison of Verified and Non-Verified Heat Strip Impacts

Similar to the section above, Guidehouse has also estimated the heat strip savings impact for sites that did not receive a visit from Franklin Energy (i.e., non-verified sites). Below provides a graphical summary of the estimated DR impact of heat strip curtailment for 15 EM&V events called in the winter of 2021/2022. Each vertical bar represents the average estimated event impact for sites that received a verification visit (in green) and for sites that did not receive a verification visit (in yellow). The 90% confidence interval is identified by the whiskers.

Figure B-2. Heat Strip Event Impacts – Verified & Non-Verified Sites



Compared to water heaters, differences in curtailment outcomes for heat strips are more pronounced for sites that received a verification visit compared to those that did not receive a verification visit. On warmer days, differences in curtailment are minimal, with at most a 0.01 kW difference identified between sites that received a verification visit and sites that did not receive a verification visit, and this difference was not identified as statistically significant. Differences in impacts are more pronounced when comparing curtailment outcomes during colder events, where observed curtailment for sites that received a verification visit was 0.42 kW per participant and curtailment for sites that did not receive a verification visit was 0.35 kW per participant. Guidehouse identified statistically significant differences between the two curtailment estimates on colder days. On average across all events observed curtailment for sites that received a verification visit was 0.31 kW per participant, while curtailment for sites that did not receive a verification visit was 0.27 kW per participant, and Guidehouse did not identify statistically significant differences in curtailment between the two groups of participants.

The same information presented in the figure above can be seen in the table below.

Table B-2. Heat Strip Event Impacts – Verified & Non-Verified Sites*

Event Type	Participant Group	Avg. Impact per Participant (kW)	Avg. Margin of Error (90% CI)	Relative Precision +/- % (90% Confidence)
All Days	Verified Sites	0.31	0.04	13%
	Non-Verified Sites	0.27	0.03	11%
Coldest Days**	Verified Sites	0.42	0.05	11%
	Non-Verified Sites	0.35	0.03	9%

*Average impact per participant, average margin of error, and average relative precision are calculated by taking the average of each of the three metrics across all events called.

** The coldest events considered are the events with average in-event temperatures at or below 23 degrees Fahrenheit.

Source: Guidehouse analysis

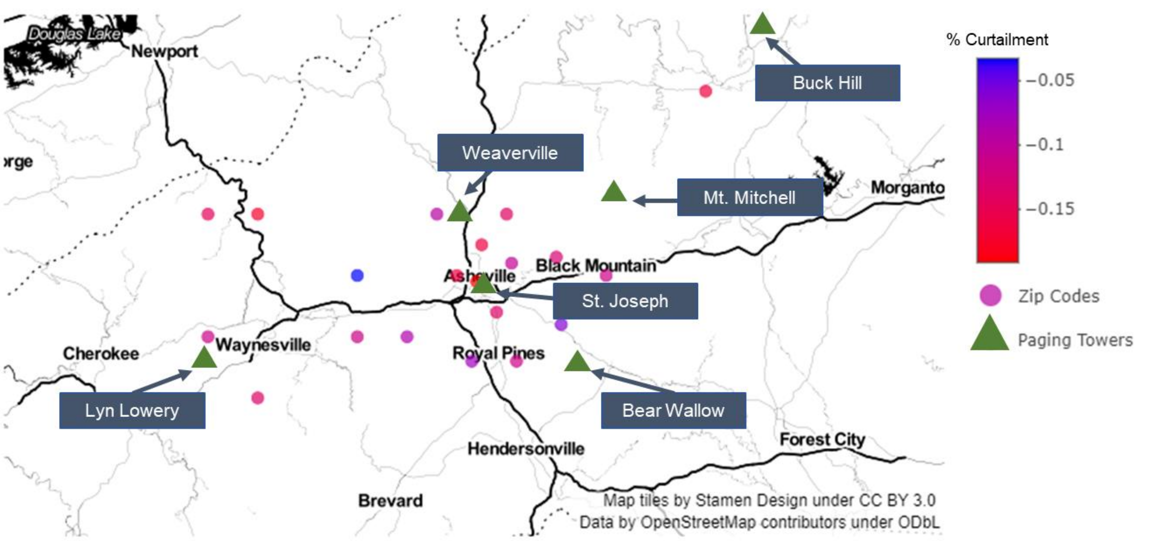
Duke Energy should not interpret differences in curtailment between the two groups as being attributed to verification alone. Of particular concern is the fact that load profiles for sites that received a verification visit were markedly greater than load profiles for sites that did not receive a verification visit (presented in Section 3.1.3). Characteristics that may be associated with greater energy usage (e.g., larger home size), and these systematic differences may also be correlated with curtailment outcomes during DR events. As such, Guidehouse urges Duke Energy to exercise caution in comparing impacts between sites that received a verification visit and sites that did not receive a verification visit.

C. Comparison of Curtailment by ZIP Code

Guidehouse provided potential causes of reduced impacts in Section 3.5.3, with one potential cause being reduced paging network performance. To assess whether differences in paging network performance may be linked to curtailment outcomes, Guidehouse provides percentage curtailment outcomes during DR events by ZIP code. These curtailment outcomes were derived by calculating the average percentage difference between baseline demand (i.e., demand for households without a controlled device during a DR event) and curtailed demand (i.e., demand for households with a controlled device during a DR event) for participants that received an appliance data logger from MadDash and a verification visit from Franklin Energy.

Figure C-1 provides percent water heater curtailment across 24 EM&V events by ZIP code. ZIP codes are color-coded depending on curtailment performance, with blue indicating lower curtailment and red indicating higher curtailment. In addition, six paging towers used to communicate with switches are labeled. For the winter 2021/2022 evaluation period, curtailment ranged from 3% to as much as 19% of baseline household consumption. Curtailment outcomes were lowest in ZIP codes immediately surrounding the Bear Wallow paging tower (28704 and 28730 with 7.7% and 6.1% curtailment, respectively) and in one ZIP code west of Asheville (28748 with 3.3% curtailment). Curtailment outcomes were otherwise comparable across the remaining ZIP codes and often ranged from 10% to 16% of baseline demand.

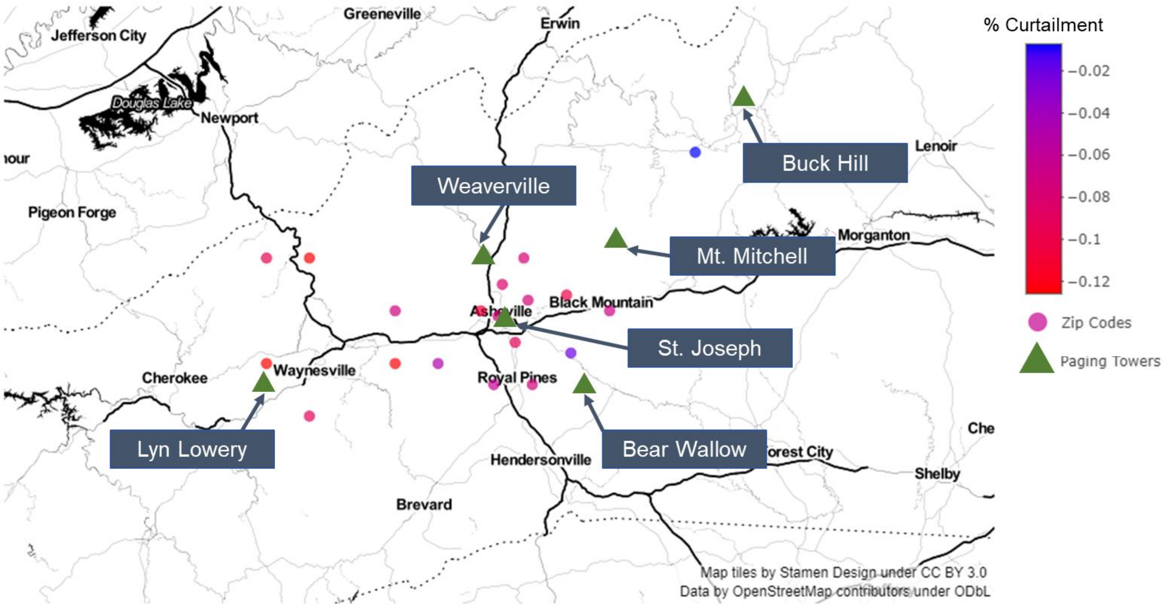
Figure C-1: Percent Water Heater Curtailment during DR Events by ZIP Code



Source: Guidehouse analysis

Figure C-2 provides percent heat strip curtailment across 15 EM&V events by ZIP code. ZIP codes are color-coded depending on curtailment performance, with blue indicating lower curtailment and red indicating higher curtailment. In addition, six paging towers used to communicate with switches are labeled. For the winter 2021/2022 evaluation period, curtailment ranged from 0.7% to as much as 12.6% of baseline household consumption. Curtailment outcomes were lowest in one ZIP codes immediately surrounding the Buck Hill paging tower (28777 with 0.7% curtailment) and in two ZIP codes just outside of Asheville (28715 and 28730 with 4.8% and 2.1% curtailment, respectively). Curtailment outcomes were otherwise comparable surrounding Asheville (between 7.5% and 10.5% of baseline demand) and greatest for ZIP codes west of Asheville (28721, 28751, and 28716 with curtailment of approximately 12.5% of baseline demand).

Figure C-2: Percent Heat Strip Curtailment during DR Events by ZIP Code



Source: Guidehouse analysis

Based on investigation of curtailment by ZIP code, it appears that some lower-performance sites tended to be clustered into a handful of ZIP codes. For water heaters, lower-performing ZIP codes were predominately near the Bear Wallow paging tower, which was offline for events called in the period spanning January 26 through February 17, and one ZIP code was just west of Asheville. For heat strips, lower-performing ZIP codes were found just outside Asheville (consistent with the Bear Wallow paging tower being offline for numerous events) and near the Buck Hill paging tower, which had no known issues during the winter 2021/2022 evaluation period.

D. Demand Response Impacts Spreadsheet

Guidehouse has provided the demand response impacts spreadsheet as a separate document.

E. Water Heater Load Shapes

Guidehouse has provided water heater load shapes in a separate PDF document.

F. Heat Strip Load Shapes

Guidehouse has provided heat strip load shapes in a separate PDF document.

G. Water Heater Curtailment by ZIP Code

Guidehouse has provided average water heater curtailment by ZIP code in a separate HTML document.

H. Heat Strip Curtailment by ZIP Code

Guidehouse has provided average heat strip curtailment by ZIP code in a separate HTML document.

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