Heat Pump Impact Evaluation

Final Report

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APPENDICES

Heat Pump Impact Evaluation Final Report

New York State Energy Research and Development Authority

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APPENDIX A. LITERATURE REVIEW

DNV (formerly ERS) submitted to NYSERDA a memorandum summarizing literature review methods and findings on February 3, 2020. A copy of the literature review memo is included in this appendix.

Heat Pump Recommendations with Secondary Research

To: Tracey DeSimone, NYSERDA

From: Kevin Boyd and Jon Maxwell, ERS

Date: February 3, 2020

This memo details the findings and recommendations from secondary research on heat pump measurement and verification for the NYSERDA Heat Pump Impact Evaluation study. The evaluation is expected to include ductless mini-split heat pumps (DMSHPs), air source heat pumps (ASHPs), and ground source heat pumps (GSHPs).

Reviewed Sources

The evaluation team selected a total of 10 sources for detailed literature review. The appendix at the end of this memo includes the titles and authors of these documents, as well as a brief summary of the source's findings and a more detailed review of each document.

In addition to the literature review, the evaluation team conducted an hour-long phone interview with heat pump experts Hugh Henderson at Owahgena Consulting and Adam Walburger and Carina Paton at Frontier Energy, and shorter conversations with David Korn at Ridgeline Analytics and Ben Schoenbauer at Center for Energy and Environment. These experts provided additional advice about the most important data streams to acquire, potential site issues, and recommendations for which information would most benefit from inclusion in an evaluation study. These recommendations have been incorporated into the following sections.

Site Work Recommendations

Based on the secondary research conducted, the evaluators recommend the following strategies for accurately assessing the impacts of heat pump projects.

- **Long-term amperage metering** of heat pump equipment is a requirement and represents standard practice for on-site heat pump metering, based on the literature review. Spot measurements of voltage and power factors paired with long-term input amperage metering is recommended for the following parameters:
  - Compressor circuit
  - Distribution fan circuit
  - Pumping circuit, if separate, for ground source systems
  - In systems with separate and/or auxiliary central heating and/or cooling systems, the compressor and combustion fan circuits, if applicable

- **Spot measurements of combustion equipment efficiency** provide an idea of the expected auxiliary heating system efficiency if it is a fossil fuel fired system, and the baseline AFUE if this is the system for which operation is being displaced by the heat pump.
- **Collect detailed nameplate and configuration data** including capacities, staging, control points, installation date, and thermostat setpoints and setbacks.
  - In heat pump systems, data for distribution fans, pumps, and heat pumps will allow the evaluators to determine nameplate efficiencies and assess in situ deviation from those nameplate values.
  - For auxiliary heating and cooling systems, this data will allow the evaluators to determine the fuel source and amount of displaced heating energy usage, as well as accurately assess the appropriate baseline for each site.
- **Collect site data** including heat pump usage data from occupant behavioral interviews, ACCA Manual J data (including envelope loads and interior gains) for the space served by the heat pump, and general site information (e.g., vintage of home, area of home, location, type of building, thermostat type, and wiring) for post-hoc categorical analysis.
  - Note: Review of the design documents for some sites may yield data such as loop size, manual J calculations, and other valuable data. The Project Completion Record should be reviewed thoroughly for each site prior to the site visit.
- **For sites using batch delivered fuels** (e.g., fuel oil, propane, wood, pellets), delivery billing data should be collected during the site visit if it was not collected prior to the visit.
- **For sites that have trend data**, which is gathered by at least one vendor, trend data for up to 1 year of operation should be collected for comparison and corroboration with metered data.

This on-site approach is considered standard and is well-supported by the literature review.

We are also proposing more intensive metering for a selection of 12 sites, with the aim of providing more detailed operating data and more information about potential focus areas for future study. We recommend including the following for the more intensive metering:

- **Spot measurements of airflow rates**, particularly on DMSHP and ASHP projects, to aid in disaggregating fan and overall system amperage, allowing for a better understanding of the proportion of unit energy usage attributable to distribution. For ductless systems, a balometer (flow hood) will be deployed over the entire outlet airstream of the unit, and current and flow velocity traverses will be conducted for different fan speeds. The team will use this spot measurement of airflow rates and current to determine long-term airflow rates based on current metering.

- **Additional long-term metering** to provide more data about the in-situ operating efficiency and actual heating and cooling capacity of the system coil. We recommend metering the following data points:
  - Temperature metering of the space temperature and supply air temperature ensures that heating operation and cooling operation are correctly identified.
  - Power metering, rather than amperage metering, of the heat pump system. This will provide long-term information on power factors, which are expected to vary across different temperatures and operation types.
  - For all unit types, supply and return air temperature and relative humidity before and after the heating and cooling coils and separate sub-metering for supply fans if necessary. This will allow the calculation of change in enthalpy across the indoor refrigerant coil, providing a more site-specific value for unit COP.
  - For GSHPs, supply and return ground source loop temperatures and separate sub-metering for pump power, if necessary.

Analysis Recommendations

The literature review highlighted the following critical components for determining savings in heat pump evaluations:

- Determining the baseline should be completed on a case-by-case basis. For some homes, a code efficiency DMSHP may be the most appropriate baseline choice, while for others the auxiliary heating system may be better. None of the evaluations that were examined used a dual baseline methodology, but this is an option that should be considered for early replacement projects.
- For displacement applications where only part of the preexisting heating and cooling load are displaced by heat pump operation, care must be taken to accurately identify the staging and control methods used to calculate the utilization ratio of the heat pump system.
- System coefficient of performance (COP) is critically important for determining the performance of a heat pump relative to the baseline; nameplate data, particularly seasonal ratings like HSPF and SEER, are consistently not representative of the actual performance of installed systems. Because the installed efficiencies are derated from nameplate efficiencies, certain baseline efficiencies should also be derated from the baseline nameplate efficiency. This highlights the need to assess system COP for at least a sample of sites.

  - The 2017 WaterFurnace field test results provided by Frontier used an alternate methodology of calculating an approximate COP based on the observed energy input to the heat pumps on-site and an assumption that weather-normalized heating loads were unchanged from the pre-project fossil fuel usage. This method provides a way to calculate approximate heating system COP for all sites, even those without the more intensive on-site metering equipment.
- Pump and fan energy are not adequately accounted for in nameplate data and are widely variable by site, so assessing pump and fan energy is important.
- Savings for fuel switching projects should be reported not only in terms of kWh penalties and fuel MMBtu savings, but also overall site MMBtu savings.
- Summer and winter peak kW impacts should be quantified to better assist in calculating the grid effects of widespread adoption of heat pumps across New York State.

After reviewing the 2019 white papers and TRM draft methodology for calculating savings for heat pumps, the evaluators plan on using the algorithms proposed in those documents to calculate savings. The parameters required for each of the TRM draft methodologies are summarized in Table 1, below.

Table 1. TRM Algorithm Parameters

Parameter	Parameter Meaning	M&V Methodology	Air Source Heat Pump	Ground Source Heat Pump
AFUE_baseline	Baseline equipment AFUE	Spot measurement of combustion efficiency; code baseline as needed	x	x
BCL	Building cooling	Manual J calculation, from application, or TRM table	x	x
BEFLH_cooling	Building equivalent full load hours for cooling	Manual J calculation, from application, or TRM table	x	x
BEFLH_heating	Building equivalent full load hours for heating	Manual J calculation, from application, or TRM table	x	x
BHL	Building heating load at design conditions	Manual J calculation, from application, or TRM table	x	x
CF	Coincidence factor	Assumed to be 0.69 based on TRM methodology	x	x
COP_season_ baseline	Seasonal COP for the baseline equipment	1 for electric resistance heat; otherwise, follow heat pump methodology	x	x
COP_season_ ee	Seasonally adjusted COP of efficient equipment	Nameplate data for rated values; calculated based on on-site metering	x	x
EER_baseline	Electric cooling energy efficiency rating for baseline equipment	Baseline efficiencies in TRM, as defined on a site-specific basis	x	x
EER_ee	Electric cooling energy efficiency rating for efficient equipment	Nameplate data for rated values; calculated based on on-site metering	x	

Parameter	Parameter Meaning	M&V Methodology	Air Source Heat Pump	Ground Source Heat Pump
EER_season_ee	Seasonally adjusted energy efficiency ratio of efficient equipment	Nameplate data for rated values; calculated based on on-site metering	x	x
EER_GLHP_full	Full-load energy efficiency ratio of GSHP at AHRI rated conditions	AHRI		x
F_CEC	Central cooling equipment factor	1 if present	x	x
F_EH	Fossil fuel system replaced by heat pump with supplemental resistance heating	1 if central electric heating system present	x	x
F_EH_new	Supplemental resistance heat requirement factor to meet peak load	1 if required	x	
F_FFH	Fossil fuel fired heating system factor	1 if present	x	x
F_load_cooling	Lookup based on cooling equipment sizing and control parameters	Factor as provided by TRM table, or calculated on a site-by-site basis using white paper methodology and on-site utilization factor	x	
F_load_heating	Lookup based on heating equipment sizing and control parameters	Factor as provided by TRM table, or calculated on a site-by-site basis using white paper methodology and on-site utilization factor	x	

APPENDIX: LITERATURE REVIEW DETAILED NOTES

The evaluation team selected 10 sources out of the documents reviewed for inclusion in the detailed literature review. Below is as a brief summary of each source's findings, with a more detailed review of the literature considered in Table A-1, below.

- **Analysis of Water Furnace Geothermal Heat Pump Sites in New York State with Symphony Monitoring Systems, Frontier Energy, December 2017.** This study included 49 residential GSHPs in upstate New York with 12 months of data from onboard monitoring systems. Major findings include the fact that pumping energy had a highly variable impact on energy usage, ranging from 3% to 30% of overall energy usage. The study found that there were some bias errors of onboard monitoring systems, resulting in under-reporting of power for dual capacity systems, over-reporting of power for variable speed system, and over-reporting of loop flow for all systems. Reported SEER was found to be higher than metered SEER.
- **Evaluation of Cold-Climate Heat Pumps in Vermont, Cadmus, November 2017.** This study of 77 heat pumps in 65 Vermont homes, paired with a survey of 135 homeowners, found wide variability in heating and cooling system usage and concluded that most sites did use other heating systems in addition to the heat pump. In addition, the report stated that heat pumps most often displaced fuel oil, propane, and wood usage in Vermont. The evaluation defined cooling baselines based on homeowner interviews and found a small overall cooling savings.
- **Ductless Mini-Split Heat Pump Impact Evaluation, Cadmus, December 2016.** This study that assessed DMSHPs among 132 homes in Massachusetts and 20 in Rhode Island found that not all units were used for each season and many were only slightly used. The evaluation identified wide variability in full load hours for heating, with the top quartile of systems hitting approximately the TRM EFLH values and the average about 60% less. On average, cooling equipment operated for fewer hours than the TRM EFLH value, but the top quartile of systems operated ~40% more frequently. This evaluation calculated net site energy savings in MMBtu and found that measured HSPF and SEER values were highly variable but significantly lower than nameplate values on average, with the largest deltas being due to behavioral differences (e.g., only using the system to aid in cooling on the hottest days). The study noted that baseline efficiencies must also be derated to match these behavioral differences.
- **White Paper Savings Calculations for Residential Air Source Heat Pumps: The Basis for Modifying EFLH and Seasonal Efficiency Factors for "Whole House" and "Displacement" Applications, Frontier Energy, September 2019.** This paper discusses bin analysis methodology for determining the portion of the total heating load that can be

attributed to ASHPs in all applications. The study recommends that Manual J calculations should be used to determine design load, and minimum and maximum loads should be based on the nameplate data. A utilization ratio must be defined for displacement applications to determine the point at which load sharing between the auxiliary heat and the heat pump begins. It also provides details about degradation of system COPs based on cycling losses and defrost degradation.

- **White Paper: Savings Calculations for Residential Ground Source Heat Pumps, Frontier Energy, August 2019.** This is a companion document to the ASHP white paper above and discusses more details on the system sizing adjustment protocols that should be used for determining system sizing. In this paper, the evaluators found that ASHRAE and ISO rated efficiency values for GSHPs do not include fan or pump power, so these must be metered and corrected for when calculating in situ efficiencies. Constant speed pumps and high static pressure PSC fans perform significantly worse than variable speed pumps and EC motors when paired with variable speed compressors.
- **Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps, Fairey et al, 2004.** This study provides more details on the calculation of SEER and HSPF rated values and notes that they are impacted by different outdoor air conditions. ARI testing procedures at the time of publication assumed no defrost operation below 17°F, and capacity of the system is defined relative to the actual design load. The study found that low coil airflow decreases operating efficiency in heating mode and results in higher auxiliary heat usage. In NYC, weather analysis suggests HSPF is 20% lower in situ than the nameplate value.
- **Memorandum: Ductless Mini-Split Heat Pump (DMSHP) Final Heating Season Results, Cadmus, 2015.** This study provides further details about site monitoring choices that were completed for the site visits that resulted in the DMSHP evaluation report mentioned above. The evaluators calculated the heat transfer rate of the interior unit using spot airflow measurements correlated with interior unit fan amperage, as well as interior temp/rh meters installed on the inlet and outlet of each head. They developed SEER and EER values based on the delta enthalpy and corrected volumetric flow rate and found that the population of units were operating at a lower percentage of full load than expected across different outdoor air conditions. The study defined baseline efficiencies for DMSHPs based on minimum typical observed efficiency in the marketplace, which was slightly higher than code.
- **Memorandum: Ductless Mini-Split Heat Pump (DMSHP) Cooling Season Results, Cadmus, 2016.** This study provides further details about site monitoring choices for the DMSHP evaluation report above. Using homeowner interviews, the evaluators found that

most DMSHPs were purchased for heating and cooling, some for cooling only, and few for heating only. Even "cooling only" customers still used the systems for heating. This study defined baselines as a code minimum DMSHP.

- **Field Assessment of Cold Climate Air Source Heat Pumps (ccASHPs), Schoenbauer et al, 2016.** This study included an intensive metering of three cold climate ASHP systems that were installed and monitored during the winter, and which were designed to allow switching between HP and auxiliary heating over different periods of the study. Integration between ccASHP and existing auxiliary heat sources was complex, and single speed fans reduced the performance of the HP systems significantly.
- **Presentation – ccASHPs and GSHPs: Savings Calculations Field Test Results, and Implications for Impact Evaluation, H. Henderson, Nov 2019.** This presentation provides details about the findings and feed-forward recommendations about GSHP and ASHP evaluation. The evaluators noted that for both GSHP and ASHP systems, information must be available regarding Manual J sizing for a building as well as rated unit nameplate data like capacity and operating power. Additionally, pumping and fan energy absolutely needs to be monitored to get a full picture of system performance. The study found that HSPF rating is not a good predictor of seasonal performance in cold climates.

Table A-1. Detailed Notes for Document Review

Document	Date	Exec Summary Review Notes	Deeper Review Notes (If applicable)
Analysis of Water Furnace Geothermal Heat Pump Sites in New York State with Symphony Monitoring Systems	2017	- 49 residential GSHP in upstate NY - 12 months of data from onboard monitoring system - 3 sites had verification of onboard monitoring data and found +-10% discrepancy with onboard reporting - Found that loop temps were really important for calculating COPs - Found that pumping energy had an outsized impact at sites without proper commissioning (3%–30% of compressor energy) - On-site verification of bias errors of onboard power systems for WaterFurnace units with Symphony reporting indicated -10% discrepancy (underreported power) for the compressors of dual capacity systems and +10% discrepancy for the variable speed system. - Found that pumping power was not reported properly because it uses a lookup table based on user-entered pump details, but these details were not input accurately. - Found that loop flow was over-reported by 7% to 17% depending on the system - The above errors resulted in a higher reported SEER than suggested by the actual metering - Systems are sized so that the aux element uses ≤ 10% of total power use; this was borne out in the data (six sites had aux heater using more than 500 kWh/yr) - Found in general that measured COPs were different than the expected COP	

Document	Date	Exec Summary Review Notes	Deeper Review Notes (If applicable)
Evaluation of Cold Climate Heat Pumps in Vermont	2017	- 77 heat pumps in Vermont at 65 sites were metered - Survey of 135 homeowners - Found fairly wide variability in heating and cooling use and EFLH - Found that systems were rarely the only heating system at a site - Found that sample size of 65 sites was OK for heating, but not for cooling, to achieve 90% CI at 20% precision. - In VT, heat pumps replaced electric resistance (7%), propane (25%), fuel oil (46%), and wood (22%) system operation - Defined 4 baselines for cooling systems based on interviews - no previous cooling, fans only, window AC, and a 14.5 SEER cooling system. Found a slight overall cooling savings	
Ductless Mini-Split Heat Pump Impact Evaluation (MA and RI)	2016	- 132 MA homes and 20 RI homes that used ductless mini split heat pumps - Differentiated between cold-climate units (78 sites) and non-cold-climate units (74 sites), as well as single head sites (107) and multi-head sites (45) - Found that not all units were used routinely for each season. Many units were only slightly used. - Found that average EFLH for winter 2015 and winter 2016 were similar (442 and 451 hr), and lower than the TRM value of 1,200 EFLH. However, the top 25% of measured EFLH were closer to the TRM values. Long tail and right skewed distribution on the heating EFLH, with minimum at ~0 EFLH - Found that the average EFLH for summer 2015 was 218 hr, with the top 25% averaging 499 hr. Compare to the TRM value of 360 hr. Long tail on cooling EFLH, with min at ~0 EFLH - Found that on times were in the 19%–27% range, with the remaining time idle - Found that average capacity was in the ~60% range for winter, and in the ~50% range for summer - Calculated net energy savings in MMBtu, in addition to savings of the baseline fuel and electric penalty - Looked at a range of baseline systems, including [furnaces, boilers, 2 efficiencies of ductless mini split heat pumps, electric resistance] for heating and [window AC, central AC, and 2 efficiencies of ductless mini splits] for cooling - Calculated HSPF and COP values for units based on the outdoor air temps and compared to rating	
Poster- Evaluation of Verifying Cold Climate Air Source Heat Pumps in Electrically Heated Residential Homes in Ontario, Canada	2017	Minimal info on poster, but follow up on the report should be complete. 2 pilot projects with AMI analysis, but only phase 2 planned on having on-site metering.	Not recommended - follow up on report
Establishing the Energy Performance of Mini-Split and Central Air-Source Heat Pumps through Billing Analysis	2018	- Fairly small paper - Found that mini split heat pumps were significantly more popular in the Nova Scotia area, where the study was based - Used a basic linear regression model based on heating degree days - Assumed constant baseline consumption	Not recommended
NEEP Variable Refrigerant Flow (VRF) Market Strategies Report	2019	- Descriptive summary of market strategies for CRF multi splits, which are primarily aimed at commercial heating and cooling applications. - Info about market strategies and efficiency criteria	Not recommended

Document	Date	Exec Summary Review Notes	Deeper Review Notes (If applicable)
Air-to-Water Heat Pump Demonstration Project	2019	- 5 sites were studied with different configurations - Note that air-to-water heat pumps are not a direct replacement for a boiler due to temperature output restrictions (130°F) - Used to completely displace heating loads in outdoor air temps above 25°F, partially down to 10°F, and not at all below 10°F OAT - Extensive notes on metering the equipment-heat pump loop temps in and out, static pressure, tank inlet and outlet temps, boiler and heat pump electrical energy, variable speed pumping energy, temperatures of supply from boiler and before supply zones - Noted defrost cycles as times when heat delivery is very low. Defrost cycles lower COP - Found that heating COP is dependent on OAT, peaking at around 3 COP at 60°F - Uses a tank temp reset based on OAT - Another system using a CO2 working fluid (capable of producing up to 170°F intermittently) - Finding: across the five sites, seasonal COPs are less than 2.0, which is lower than mfr published data	Not recommended unless air-to-water system is discovered in our sample
Ramping Up Heat Pump Adoption in New York State: Targets and Programs to Accelerate Savings	2018	Discusses policy options and process recommendations for improving heat pump program offerings and pushing hard on electrification.	Not recommended for evaluation planning
NEEP Guide to Sizing & Selecting Air-Source Heat Pumps in Cold Climates	2018	- Referenced in the NY TRM. - Discusses strategies for calculating loads and selecting equipment. - May be valuable for technology training on this project but does not offer much input on on-site evaluation strategies	Only recommended to review for training
BG&E "Development of Residential Load Profile for Central Air Conditioners and Heat Pumps"	2011	Used for calculating coincidence factors in the NY TRM	Not reviewed

Document	Date	Exec Summary Review Notes	Deeper Review Notes (If applicable)
Henderson, H.I., 2019. White Paper Savings Calculations for Residential Air Source Heat Pumps: The Basis for Modifying EFLH and Seasonal Efficiency Factors for "Whole House" and "Displacement" Applications. Prepared for the New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of Public Service.	2019	- Referenced in the NY TRM for calculating EFLH values. Very important as it details information on calculating EFLH for systems that are displacing operation of another system. - Uses a bin analysis of all ASHPs in the database to inform factors for TRM calcs. - Bin analysis method determines the portion of the total heating load that can be attributed to the ASHP in all applications - Design load is calculated based on Manual J calcs, and minimum and maximum capacities are calculated and extrapolated out based on the nameplate data. - The delivered capacity is bounded at the top by the maximum capacity. - For operation below the minimum capacity, part load/cycling losses are assumed, which reduces the COP of the system. Look at page 5 for the part load losses equation - Defrost degradation is included in HSPF- different defrost degradation factors at different temps. Assumes linear interpolation between the points listed to find the factor in each bin. Central ducted systems with resistance elements that turn on during defrost multiply the defrost factor by 1.5; ductless units do not use resistance elements during defrost typically (in favor of a reverse cycle). 1.5 factor is based on 5 min of each hour for defrost cycles, base COP is 2.5 - Important for displacement applications: utilization ratio (UR). Defined as the value when the building load reaches (UR)% of the maximum ASHP capacity, at which point load sharing begins. This is due to assumed inefficiencies in the way heat is distributed around the building. No default value is offered. UR = 1.0 is when a heat pump's capacity can serve the building load over the range of outdoor design temps; backup heat only comes up when load exceeds the max capacity at temperature T. UR = 0.0 would be full load sharing across all temps. UR = 0.35 would be a case where once the building load is >35% of the HP capacity, load sharing begins- this is not the same as 35% of the load being met! - Provides a detailed set of analysis results for correcting rated HSPF to predicted HSPF based on fraction of loads and UR values	
Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps	2004	- Discusses how SEER and HSPF are impacted by different outdoor air temperatures. - Air handler fan power is not included in the input energy use - Notes that DOE-2 (and eQUEST) use EIR, which is 1/COP excluding the fan power - Notes that the ARI testing procedure assumes a 65°F interior temperature, though the researchers found that a more common setpoint for interior temp was 68°F - Researchers found that the ARI test protocol defines capacity of the system relative to the actual design load, which is reduced by 23% to account for solar and internal gains - Heat pump defrost in modern units should include demand defrost; however, some ASHPs use a compressor timers that activate up to 10 minutes of defrost cycle every 50-90 minutes of operation - ARI test procedure assumes no defrost operation below 17°F, even though this is not likely the case - Aux strip heat during the defrost cycle in ducted units may be used to prevent "cold blow," though this is not included in the ARI protocol - Notes that low coil airflow will significantly impact system operating efficiency in heating mode and result in increased aux heat - Found that in NYC, % decrease in HSPF was approximately 20% lower than the nameplate (a 7.8 HSPF/12 SEER unit operated at 6.5 HSPF/11.0 SEER	

Document	Date	Exec Summary Review Notes	Deeper Review Notes (If applicable)
Ductless Mini-Split Heat Pump Cooling System Results- Memorandum	2016	- Study includes details on 152 MA and RI homes - Wanted to find comparison between in situ performance and rated cooling cap, seer, EER, and ambient conditions - Provides details on how the evaluation team figured out heat transfer rate of the interior unit: spot measurement of airflow, combined with spot measurement of the fan current in A. Current was then used as a proxy for each make and model of indoor head observed in the study to make curves. Took spot airflow measurements at each speed setting on the indoor head for 1-3 minutes using a balometer (flow hood with a specialized frame) to capture all the airflow out of the unit. CTs were installed directly on fan wires, which are in the outdoor unit. - Team measured a delta enthalpy for each unit using several temp/rh meters installed on the inlet and the outlet of each head. - SEER and EER was then calculated for each unit by looking at the heat removed (based on delta enthalpy and corrected volumetric flow rate based on the amperage data) and the power input - Found that the population of DMSHPs operated at 12% of FL kW at 70°F OAT, 30% of FL at 80°F, and 70% of FL at 95°F. - kWh was calculated based on tons, hours, and 1/SEER values for the baseline and EE cases - EFLH was calculated based on total seasonal kWh and nameplate peak demand - Baseline was based on not only the code minimum, but also the minimum typical observed efficiency in the marketplace	
Ductless mini-split heat pump heating system results- memorandum	2015	- Found that most DMSHPs were purchased for a combination of heating and cooling (65%), with some (31%) for cooling only and fewer (4%) for heating only - Even "cooling only" intention customers used the systems for heating, at a rate of 40% of the usage of participants who bought them for heating and cooling - Used code minimum DMSHP (HSPF of 8.2) for baseline	
ccASHPs and GSHPs: Savings Calculations, Field Test Results, and Implications for Impact Evaluation (presentation)	2019	- Discussion of GSHP and ccASHP approach in an evaluation - TRM-compatible calc procedure - For GSHP: need to know rating for unit, Manual J, and installed pumping - For ccASHP: need to know HSPF, type of ccASHP, manual J, and sizing - Building EFLH (BEFLH) was found to be insufficient- instead ACCA Manual J design heating load (based on 99% design temp for each city) - Theoretical BEFLH values are based on linear model for heating load, with 100% @ design conditions, balance point is 57.5°F - Found info on ground loop temperatures - average EWT for upstate was 40°F, with 95% CI from 30°F to 50°F. 1F change in EWT changes heating COP by 1%! - Note that NEEP ccASHP standards mandate variable speed, COP @ 5°F (and at max speed) of >1.75; HSPF >10 for ductless and >9 for ducted. HOWEVER, noted that HSPF is a bad predictor of seasonal performance in cold climates - Found that a system sized for 50% of building loads meets 36% of seasonal loads in Albany - Found that there was similar EWT and LWT for horizontal and vertical ground loops - Tons of instrumentation used on GSHP systems that use the Symphony dataset - Found on multi-unit loop systems that if one pump is reversed, many others are affected downstream	

Document	Date	Exec Summary Review Notes	Deeper Review Notes (If applicable)
White paper: Savings for Ground Source Heat Pumps	2019	- Discusses more details on the system sizing adjustment protocols, from perfectly sized (heating load at 1% temp design condition) to Manual J (10% greater than perfectly sized) to Manual S (required in NY; very similar to Manual J, about 3% lower) - Found that GLHP AHRI heating capacity (in tons) is lower than the cooling capacity (in tons). GLHPc ~ 1.33*GLHPh - EFLH must be modified based on which loads are being used for both heating and cooling- this is in the new TRM methodology as correction factors - ASHRAE and ISO efficiency values do not include fan or pump power, so these need to be corrected for when calculating in situ efficiencies - Dual and variable speed systems spend a lot of time at part load conditions. Need to appropriately weight. - Notes on pump impacts - most efficient systems are variable speed pumps with variable speed compressors. Constant speed pumps are the worst. - Fan power in rated efficiency is for zero external static pressure, and so is lower than expected. Expect closer to 0.5 W/cfm for PSC motors, 0.31 W/cfm for ECM	
Field Assessment of Cold-Climate ASHPs	2016	- ccASHP field assessment from 2015-2016 heating system - 3 homes were monitored. During the winter, went back and forth between the ccASHP wish existing heating as backup, and existing traditional system only to allow comparison - Logged power consumption of the indoor and outdoor units, and defrost separately - Logged aux heating with a gas meter and watt transducer - Logged temps in mechanical room, conditioned space, outdoor air, supply duct air, and return duct air - Spot measured airflow and calibrated to fan amps for long term proxy measurement - Noted that integration between the ccASHP and existing heat sources as backup were complex, as a multi-stage of variable speed fan is necessary to achieve the full benefits of the system. - Noted possibility of behavioral differences, though it's hard to tell with only 3 sites - Noted 39%-65% of on-site Btu savings	

APPENDIX B. CUSTOMER SURVEY INSTRUMENT

DNV (formerly ERS) submitted to NYSERDA the final customer survey instrument in December 2019. A copy of the customer survey is included in this appendix.

NYSERDA HP Impact - v20191217

Start of Block: Informed Respondent

Q1 Welcome to the Survey!   This survey is being conducted on behalf of the New York State Energy Research and Development Authority (NYSERDA) as part of an important study of heat pumps installed in New York State.

According to our records, a heat pump was installed at your location since 2017.   **We need your help to learn about the performance of your heat pump, and we are offering an Amazon gift card of $15 as a thank you if you participate and complete this survey.**   During the survey, you will also be offered an opportunity to increase the Amazon gift card value to a total of $50 if you complete a Release Form to allow NYSERDA to request your energy usage data from your utility companies and/or fuel vendors for analysis. The release form will ask you for account numbers with your electric utility and any companies that provide your home with heating fuel. Please have those account numbers available.

In filling out this web survey, please use the form's NEXT and BACK buttons until the survey is completed.

If you have questions before you get started or problems while completing this survey, please contact us at 888-434-8008 or Judeen.Byrne@nyserda.ny.gov

Please enter the PIN code provided in your invitation letter, then click “NEXT” to begin the survey.

PIN1 Please enter the six-character PIN from your invitation letter.

____

Page Break

S1 Are you an HVAC installation contractor?

○ Yes (1)

○ No (4)

Skip To: I3 If S1 = Yes

S4 Please enter the address where the heat pump is installed.

○ Street Address (4) ____

○ City, State, Zip (5) ____

S5 What type of space is the heat pump installed into?

○ Home (1)

○ Non-residential facility (2)

S6 Below are images and descriptions of three different types of heat pump. Please confirm which type of heat pump was installed at your location.

○ Air-sourced (1)

○ Geothermal or Water-sourced (2)

○ Ductless mini-split (3)

○ Don't know (5)

I1 Are you familiar with the use of this heat pump and why it was purchased?

- ○ Yes (1)
- ○ No (2)
- ○ Don't know (3)

Skip To: End of Block If I1 = Yes

*

I2A Please provide the name, and phone number and email address (if you have them) of the person you think would be familiar with this heat pump installation:

- ○ Name (1) ____
- ○ Phone Number (include area code) (2) ____
- ○ Email Address (3) ____

Page Break

I3 Thank you for this information. We are sorry; you do not qualify to complete this survey. If you are interested in learning more about NYSERDA's activities, please go to the following link. https://www.nyserda.ny.gov/Researchers-and-Policymakers/Clean-Heating-and-Cooling

Skip To: End of Survey If I3() Is Displayed

End of Block: Informed Respondent

Start of Block: Measure Type

M1 We would like to ask you a few questions about this project and about the use of the new heat pump. Was the heat pump installed in a newly constructed space or ${S5/ChoiceGroup/SelectedChoices}, or was it installed in an existing space or ${S5/ChoiceGroup/SelectedChoices}?

- ○ Existing space (1)
- ○ Newly constructed (2)
- ○ Remodel or addition (5)
- ○ Other (3) ____
- ○ Don't know (4)

M2 Are you using the heat pump for heating, cooling, or both?

- ○ Heating Only (1)
- ○ Cooling Only (2)
- ○ Both (3)
- ○ Don't know (4)

Display This Question:

If S6 = Ductless mini-split

M3 How many heads does your heat pump unit have? By heads, we mean units on the walls that deliver heating and/or cooling to your ${S5/ChoiceGroup/SelectedChoices}.

- ○ One (1)
- ○ Two (2)
- ○ Three (3)
- ○ More than three (4)
- ○ Don't know (5)

Display This Question:

If M1 != Newly constructed

M4 Is the amount of heated and/or cooled floor space in your ${S5/ChoiceGroup/SelectedChoices} the same, larger, or smaller than before you installed this new heat pump?

- ○ Floorspace is the same (1)
- ○ Floorspace is now larger (2)
- ○ Floorspace is now smaller (3)
- ○ Other scenario (Please explain) (4) ____
- ○ Don't know (5)

Display This Question:

If M4 = Floorspace is now larger

Or M4 = Floorspace is now smaller

And If

M1 != Newly constructed

M5 You said that the heated and/or cooled ${M4/ChoiceGroup/SelectedChoices} than it was before you had the heat pump installed. Roughly, how many heated and/or cooled square feet larger/smaller is your current ${S5/ChoiceGroup/SelectedChoices} compared to what it was before?

○ # of Square Feet (1) ____

○ Other Scenario (Please explain) (2) ____

○ Don't know (3)

End of Block: Measure Type

Start of Block: Cooling

Display This Question:

If M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

C1

Before your new heat pump was installed, what was the ***primary equipment*** you used to cool your ${S5/ChoiceGroup/SelectedChoices}

○ A central air conditioner (1)

○ An air-source heat pump (2)

○ A ground-source heat pump (3)

○ An evaporative cooler ("swamp cooler") (4)

○ Room air conditioners (window unit) (5)

○ A ductless heat pump (6)

○ Fans (7)

○ We had no cooling equipment before we got the heat pump (8)

○ Other Scenarios (Please explain) (9) ____

○ Don't know (10)

Skip To: End of Block If C1 = We had no cooling equipment before we got the heat pump

---

Display This Question:

If M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

C2 Is the ***primary cooling system*** that you used before getting your new heat pump still being used to provide any cooling in your ${S5/ChoiceGroup/SelectedChoices}

◯ No (1)

◯ Yes, but only infrequently (2)

◯ Yes, and we still use it frequently (3)

◯ Other (Please explain) (4) ____

◯ Don't know (5)

Display This Question:

If M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

And If

C1 != Fans

C4 Thinking about your ${S5/ChoiceGroup/SelectedChoices} **in the summer**, are you keeping it cooler than you used to, warmer than you used to, or about the same as you used to before installing your new heat pump?

◯ Cooler (1)

◯ Warmer (2)

◯ Keeping temperature settings the same (3)

◯ Other (Please explain) (4) ____

◯ Don't know (5)

Display This Question:

If C4 = Cooler

Or C4 = Warmer

And If

M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

And If

C1 != Fans

C5 On average, about how many degrees ${C4/ChoiceGroup/SelectedChoices} do you keep your ${S5/ChoiceGroup/SelectedChoices} with your new heat pump?

- ○ # of degrees (1) ____
- ○ Other (Please explain) (2) ____
- ○ Don't know (3)

Display This Question:

If C1 = Room air conditioners (window unit)

And If

M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

C6 You said that before getting your new heat pump, you primarily cooled your ${S5/ChoiceGroup/SelectedChoices} using room air conditioners. Did you use these room air conditioners on all warm days, most warm days, only hot days, very rarely, or never?

- ○ All warm days (1)
- ○ Most warm days (2)
- ○ Only hot days (3)
- ○ Very rarely (4)
- ○ Never (5)
- ○ Other (Please explain) (6) ____
- ○ Don't know (7)

Display This Question:

If C1 = A central air conditioner

Or C1 = An air-source heat pump

Or C1 = A ground-source heat pump

Or C1 = An evaporative cooler ("swamp cooler")

Or C1 = Room air conditioners (window unit)

Or C1 = A ductless heat pump

Or C1 = Fans

Or C1 = Other Scenarios (Please explain)

And If

M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

C9 Is your new heat pump used to cool the same amount of space in your ${S5/ChoiceGroup/SelectedChoices} as your ***previous cooling equipment***, less space, or more space?

- ◯ About the same amount of space (1)
- ◯ Less space (2)
- ◯ More space (3)
- ◯ Other scenarios (Please explain) (4)
- ◯ Don't know (5)

Display This Question:

If C9 = Less space

Or C9 = More space

And If

M1 = Existing space

And If

M2 = Cooling Only

Or M2 = Both

C10 In percentage terms, roughly how much ${C9/ChoiceGroup/SelectedChoices} does your current heat pump cool as ***your previous cooling equipment***?

- ◯ % ${C9/ChoiceGroup/SelectedChoices} (1) ____
- ◯ Other (Please explain) (2) ____
- ◯ Don't know (3)

End of Block: Cooling

Start of Block: Heating

Display This Question:

If M1 = Existing space

And If

M2 = Heating Only

Or M2 = Both

H1 Before your new heat pump was installed, what was the ***primary equipment*** you used to heat your ${S5/ChoiceGroup/SelectedChoices} ?

- ◯ A central furnace/boiler (1)
- ◯ A central heat pump (2)
- ◯ A room heat pump (3)
- ◯ Electric resistance (baseboard) heating (4)
- ◯ Room plug-in/space heaters (5)
- ◯ Wood stoves (6)
- ◯ Fireplace (7)
- ◯ We had no heating equipment before we got the heat pump (8)
- ◯ Other scenarios (Please explain) (9) ____
- ◯ Don't know (10)

Skip To: End of Block If H1 = We had no heating equipment before we got the heat pump

Display This Question:

If H1 = A central furnace/boiler

Or H1 = Fireplace

Or H1 = Other scenarios (Please explain)

And If

M1 = Existing space

And If

M2 = Heating Only

Or M2 = Both

H1a What type of fuel did your ***previous primary heating equipment*** use?

- ○ Natural gas (1)
- ○ Propane (2)
- ○ Home heating oil (3)
- ○ Wood, wood chips, biomass (4)
- ○ Electricity (5)
- ○ Other fuels (Please explain) (6) ____
- ○ Don't know (7)

Display This Question:

If M1 = Existing space

And If

M2 = Heating Only

Or M2 = Both

H2 Is the ***primary heating equipment*** that you used before getting your new heat pump still being used to provide any heating to your ${S5/ChoiceGroup/SelectedChoices} ?

- ○ No (1)
- ○ Yes, but only infrequently (2)
- ○ Yes, and we still use it frequently (3)
- ○ Other (Please explain) (4) ____
- ○ Don't know (5)

Display This Question:

If H1 = Room plug-in/space heaters

And If

M1 = Existing space

And If

M2 = Heating Only

Or M2 = Both

H6 You said that before getting your new heat pump, you primarily heated your ${S5/ChoiceGroup/SelectedChoices} using portable room space heaters. Did you use these space heaters on all cool days, most cool days, only cold days, very rarely, or never?

- ○ All cool days (1)
- ○ Most cool days (2)
- ○ Only cold days (3)
- ○ Very rarely (4)
- ○ Never (5)
- ○ Other (Please explain) (6) ____
- ○ Don't know (7)

Display This Question:

If H1 = A central furnace/boiler

Or H1 = A central heat pump

Or H1 = A room heat pump

Or H1 = Electric resistance (baseboad) heating

Or H1 = Room plug-in/space heaters

Or H1 = Wood stoves

Or H1 = Fireplace

Or H1 = Other scenarios (Please explain)

And If

M1 = Existing space

And If

M2 = Heating Only

Or M2 = Both

H9 Is your new heat pump used to heat the same amount of space in your ${S5/ChoiceGroup/SelectedChoices} as your ***previous heating equipment***, less space, or more space?

- About the same amount of space (1)
- Less space (2)
- More space (3)
- Other scenarios (Please explain) (4) ____
- Don't know (5)

Display This Question:

If H9 = Less space

Or H9 = More space

H10 In percentage terms, roughly how much ${H9/ChoiceGroup/SelectedChoices} does your current heat pump heat compared to your ***previous heating equipment***?

- ◯ % ${H9/ChoiceGroup/SelectedChoices} (1) ____
- ◯ Other scenarios (Please explain) (2) ____
- ◯ Don't know (3)

End of Block: Heating

Start of Block: New System Controls

Display This Question:

If H2 = Yes, but only infrequently

Or H2 = Yes, and we still use it frequently

And If

S6 = Ductless mini-split

HC1 Do you have a control system that manages your mini-split heat pump system together with your **previous primary heating system**?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Other (Please explain) (3) ____
- ◯ Don't know (4)

Display This Question:

If S6 = Ductless mini-split

And HC1 = Yes

*

HC2 About what percent of the time in the heating season is your ductless mini-split heat pump being used at the same time as your **previous primary heating system**?

____

Display This Question:

If C2 = Yes, but only infrequently

Or C2 = Yes, and we still use it frequently

And If

S6 = Ductless mini-split

HC3 Do you have a control system that manages your mini-split heat pump system together with your previous primary central cooling system?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Other (Please explain) (3) ____
- ◯ Don't know (4)

Display This Question:

If S6 = Ductless mini-split

And HW3 = Yes

*

HC4 About what percent of the time in the cooling season is your ductless mini-split heat pump being used at the same time as your **previous primary cooling system**?

____

End of Block: New System Controls

Start of Block: Domestic Hot Water

HW1 What type of water heater do you have?

- ○ Tank-style (1)
- ○ Tankless ("on demand") (4)
- ○ A heat-pump water heater (8)
- ○ Side-arm (space heating boiler heats water also) (5)
- ○ Other water heater types (Please explain) (6) ____
- ○ Don't know (7)

HW1a What kind of fuel source does your water heater use?

- ○ Electricity (1)
- ○ Natural gas (2)
- ○ Propane (3)
- ○ Heating oil (4)
- ○ Wood, wood chips, other biomass (5)
- ○ Same fuel as boiler (6)
- ○ Solar (7)
- ○ Other fuel (please explain) (8) ____
- ○ Don't know (9)

HW3 Did you have to add or install any new hot ***water heating equipment*** because of the installation of your new heat pump?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Don't know (4)

Display This Question:

If HW3 = Yes

HW4 What type of ***water heater*** did you have to add?

- ◯ Tank-style (1)
- ◯ Tankless ("on demand') electric (4)
- ◯ A heat pump water heater (8)
- ◯ Side-arm (space heating boiler heats water also) (5)
- ◯ Other water heater types (Please explain) (6) ____
- ◯ Don't know (7)

End of Block: Domestic Hot Water

Start of Block: Heat Pump Installation Experience

HP1 Did you encounter any difficulties during or after the installation of your heat pump equipment?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Other (Please explain) (3) ____
- ◯ Don't know (4)

Display This Question:

If HP1 = Yes

HP2 What difficulties during or after the installation of the equipment did you encounter? [Select all that apply]

- ▢ New system is not providing adequate heating (2)
- ▢ New system is not providing adequate cooling (3)
- ▢ New system is not saving as much energy as I expected (4)
- ▢ New system was more expensive than expected (5)
- ▢ I was not shown how to operate the new system (9)
- ▢ Installation contractor was unprofessional or performed poorly (6)
- ▢ Other difficulties (please explain) (7) ____
- ▢ Don't know (8)

HP3 Since the heat pump was installed, has it needed any repairs or replacement of parts?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Other (Please explain) (3) ____
- ◯ Don't know (4)

Display This Question:
If HP3 = Yes

HP4 What repairs or replacements did your new heat pump need?

____

____

____

____

____

End of Block: Heat Pump Installation Experience

Start of Block: Billing Release Form

B1 As part of NYSERDA's evaluation, we would like to include your ${S5/ChoiceGroup/SelectedChoices}'s energy usage in our analysis of energy impacts. To do this, NYSERDA and your utility companies need consent and approval to release your energy usage data. If you agree to release your information, **you will receive an additional $35 incentive** upon validation of the provided account details. Accurate account information must be provided in order to receive the full incentive. Please allow up to 45 days to receive your incentive. Are you willing to release your energy data and fill out the consent form?

- ◯ Yes, I am willing to participate (1)
- ◯ No, I would rather not participate (3)

Display This Question:

If B1 = Yes, I am willing to participate

CON1 **Billing Information Release Consent Form**

By providing the account numbers for the property listed below, I hereby authorize the identified energy companies to release, to NYSERDA and/or its designated representatives, energy billing and consumption data for the property listed for up to the past 60 months. I understand that NYSERDA will use this data only for evaluation purposes related to heat pumps, that results will be reported only in the aggregate, and that the data obtained pursuant to the agreement will be treated as confidential to the extent permitted by law, including the Freedom of Information Law.

${S4/ChoiceTextEntryValue/4}

${S4/ChoiceTextEntryValue/5}

By providing the information below, I indicate my understanding and acceptance of these terms.

Please enter the following information from your electric bill.

- ◯ Name of electric utility (2) ____
- ◯ Account number (3) ____
- ◯ Name as it appears on account (4) ____

Display This Question:

If B1 = Yes, I am willing to participate

CON2 Please enter the following information from a bill from the company that provides (or provided) heating fuel (such as natural gas, propane, heating oil, wood, or other fuels) to your location. *If you do not or did not have any other fuel, please enter "None" in the name of the fuel provider.*

- ◯ Name of fuel provider (1) ____
- ◯ Fuel type (2) ____
- ◯ Account number (3) ____
- ◯ Name as it appears on account (4) ____

Display This Question:

If B1 = Yes, I am willing to participate

CON3 If you have or had an additional provider of heating fuel, please enter the following information from a bill from that company.

- ◯ Name of fuel provider (1) ____
- ◯ Fuel type (2) ____
- ◯ Account number (3) ____
- ◯ Name as it appears on account (4) ____

End of Block: Billing Release Form

Start of Block: Site Visits

S1 Later this year, contractors working for NYSERDA will select and visit locations that installed the **energy-efficient heat pumps** rebated through this program. You may be selected/chosen to receive a site visit. If you are selected, additional incentives will be provided for your participation.Would you be the best person to contact to coordinate this visit?

- ◯ Yes, you can contact me (1)
- ◯ I prefer not to participate (3)

End of Block: Site Visits

Start of Block: Demographics/ Firmographics

Display This Question:

If S5 = Home

DA Lastly, I would like to ask a few background questions about you and your household.

Display This Question:

If S5 = Home

D2 What kind of house do you live in?

- Single-family house (1)
- 2-family house (2)
- Apartment/condo/townhouse (3)
- Other (4) ____
- Don't know (5)
- Refused (6)

Display This Question:

If S5 = Home

D3 In approximately what year was your home built?

____

Display This Question:

If S5 = Home

D5 How many people reside in your home including yourself?

- ○ 1 (1)
- ○ 2 (2)
- ○ 3 (3)
- ○ 4 (4)
- ○ 5 (5)
- ○ 6 (6)
- ○ 7 (7)
- ○ 8 (8)
- ○ 9 (9)
- ○ 10 or more (10)

Display This Question:

If S5 = Home

D5A Is the current number of people in your home the same as it was before the heat pump was installed?

- ○ Yes (1)
- ○ No (2)
- ○ Other (Please explain) (3) ____
- ○ Don't know (4)

Display This Question:

If D5A = No

And S5 = Home

D5B How many people including yourself resided in your home **before the heat pump was installed**?

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- 6 (6)
- 7 (7)
- 8 (8)
- 9 (9)
- 10 or more (10)

Display This Question:

If S5 = Non-residential facility

DB Lastly, I would like to ask a few background questions about your company.

Display This Question:

If S5 = Non-residential facility

D6 What is the principal activity of your organization at this location?

- ◯ Agriculture/farm (1)
- ◯ Casino (2)
- ◯ College/university (3)
- ◯ Community Service/Church/Temple/Municipalty (4)
- ◯ Gas Station/Convenience store (5)
- ◯ Grocery store (6)
- ◯ Healthcare/Hospital (7)
- ◯ Industrial process/manufacturing/assembly (8)
- ◯ Office (9)
- ◯ Recreational facility (10)
- ◯ Restaurant (11)
- ◯ Retail (non-food) (12)
- ◯ School (13)
- ◯ Warehouse (14)
- ◯ Water/wastewater treatment (15)
- ◯ Other (16) ____
- ◯ Don't know (17)

Display This Question:

If S5 = Non-residential facility

Q65 In approximately what year was your building constructed?

____

End of Block: Demographics/ Firmographics

Start of Block: Information for incentive

Display This Question:

If B1 != Yes, I am willing to participate

II1a To thank you for completing the survey, we are offering a $15 Amazon gift card. How would you prefer to receive the gift card?

- ○ Email (1)
- ○ Postal mail (2)
- ○ Decline Amazon card (4)

Display This Question:

If B1 = Yes, I am willing to participate

II1b To thank you for completing the survey, we are offering a $15 Amazon gift card and an additional $35 upon verification of the authorization and account information you provided .How would you prefer to receive the gift card?

- ○ Email (1)
- ○ Postal mail (2)
- ○ Decline Amazon card (4)

Display This Question:

If II1a = Email

Or II1b = Email

*

Email1 To receive your gift card, please enter your name, email address, and phone number.Please allow up to 45 days for receipt.

○ Name (1) ____

○ Email Address (4) ____

○ Phone Number (include area code) (5) ____

Display This Question:

If II1a = Postal mail

Or II1b = Postal mail

PostalMail1 To receive your gift card, please enter your name, address, and phone number. Please allow 45 days for receipt.

○ Name (1) ____

○ Mailing Address (2) ____

○ City, State, Zip (3) ____

○ Phone Number (include area code) (5) ____

End of Block: Information for incentive

APPENDIX C. INSTALLER INTERVIEW QUESTIONNAIRE

DNV (formerly ERS) submitted to NYSERDA the final installer interview questionnaire on March 24, 2020. A copy of the questionnaire is included in this appendix.

Heat Pump Contractor In-Depth Interview Guide

Date Updated: March 24, 2020

NYSERDA Contract #: 104543

Objectives: This interview guide is designed to gather information from a stratified sample of heat pump installation contractors. Topics of interest include:

- The availability and installation of controls to optimize use of the heat pumps with secondary heating or cooling sources
- Installation problems experienced, recurring repair, or performance issues
- Conditions that are most conducive and cost-effective for heat pumps and other heating and cooling options that customers consider as part of the decision-making process
- Refrigerant material, leakage issues, and need for recharge
- Equipment sizing practices by heat pump technology, including types of sizing calculations and rules of thumb being used (i.e., ACCA Manual J)
- Insights into best and worst practices and site characteristics for most efficient heat pump operations
- Barriers to meeting New York State's aggressive goals for deploying high volumes of heat pumps rapidly

Introduction

Hello, my name is [Interviewer_name] and my company, [Company_Name], is conducting research on heat pump installation contractors on behalf of NYSERDA. We are trying to learn more about the heat pump market and how certain factors affect installation decisions. Is there someone available who I could talk to about that?

[IF NECESSARY, ADD]: "We're not selling anything, this is purely for research purposes to understand heat pump installation practices in New York."

[IF NECESSARY, ADD]: "All your responses will be kept confidential."

[IF ASKED] If you would like to verify the legitimacy of this research you can call Elizabeth Boulton at NYSERDA at 212-971-5342 x3620 . If you have questions about this or the follow-up survey, you can reach out to the study manager by calling Bradley Campbell at (608) 259-9152.

[ITERATE UNTIL YOU FIND SOMEONE KNOWLEDGABLE ABOUT HEAT PUMP SALES AND INSTALLATIONS]

Sales Process

1. To help me put your answers in context, can you give me an estimate of the number of heat pump installations your company does in a typical year?
    a. [IF ASKED] For ductless mini-split heat pumps, we would like to know both the number of projects and the typical number of units (outdoor and indoor).
2. Does [Company_Name], install both air-source and ground-source heat pumps?
    a. [IF YES] Are you the right person to talk to about **air**-source heat pumps?
        i. [IF NO] Who is the right person? [Get name and contact information]
    b. [IF YES] Are you the right person to talk to about **ground**-source heat pumps?
        i. [IF NO] Who is the right person? [Get name and contact information]
3. How does that number of heat pump installations compare to your number of combustion heating equipment installations?
    a. [IF NECESSARY, ADD]: This includes natural gas, propane, and oil boilers and furnaces.
4. How, if at all, do you help customers decide what technology to install? For example, do you present them with several different options using various technologies?
    a. What specific information do you include in these options? [PROBES:]
        i. Initial/installation cost

ii. Fuel/operation cost

iii. Lifetime cost

iv. Payback period

v. Operational characteristics such as noise or comfort

vi. Warranties

vii. Maintenance costs or expectations

viii. Testimonials

ix. Applicability of manufacturer, government, utility rebates or low-cost financing (i.e. GJGNY)

x. Other (Specify)

5. Are there any particular conditions or situations where you'd recommend a heat pump over a combustion heating system?
[PROBES:]

    a. Climate
    b. Availability of gas or non-electric heating fuel
    c. Cost of gas/non-electric heating fuel
    d. Availability of backup heating
    e. Home or commercial building size
    f. Desire to add cooling where there previously was none
    g. Presence or lack of existing distribution system(s)
    h. Other (Specify)

6. What information influences customer decisions about what technology to install?
[PROBES:]

    a. Initial/installation cost
    b. Fuel/operation cost
    c. Lifetime cost
    d. Payback period
    e. Operational characteristics such as noise or comfort
    f. Warranties
    g. Maintenance costs or expectations
    h. Testimonials

i. Applicability of manufacturer, government, utility rebates or low-cost financing (i.e. GJGNY)

i. Other (Specify)

Installation Process

1. When installing a heat pump, what types of sizing calculations do you use (e.g., ACCA Manual J)?
   [PROBES:]
   a. Do you use any shortcuts or rules of thumb? [GET DETAILS]
   b. Do sizing practices differ for different types of equipment? (e.g., Ducted vs. non-ducted Air Sourced vs. Ground-sourced heat pumps, etc.) [GET DETAILS]
   c. Are there any flow sizing considerations?

   [Background for interviewers: This is important to know because airflow requirements for a new heat pump AHU will not always be the same as an existing furnace AHU which may lead to efficiency and comfort problems later.]
2. How often do you install controls to optimize use of the heat pump with secondary heating or cooling sources? Would you say: never; rarely; sometimes; often; always?
   a. [IF LESS THAN ALWAYS] What factors determine when you install or don't install optimization controls?
   b. What are typical optimization controls and settings?
      i. How do you determine what is optimal for a site and system?
3. How often do you experience installation problems with heat pumps? How does that compare to combustion heating systems?
   a. What problems do you typically encounter?
   b. To what extent do new heat pump installations require electrical panel upgrades?[PROBE FOR DETAILS]

      [NOTE TO CALLERS: Electrical issues have been a concern with GSHP installations. Gathering more information from the contractors will be helpful here.]

Operations and Maintenance

1. Are there any common issues that require service callbacks after installation? [PROBE FOR DETAILS]
2. How often do you need to do service calls for refrigerant material, either due to leakage issues or need for recharge?

a. How does that compare to the frequency of service calls for more traditional heating and cooling systems?

b. What refrigerants are used most frequently in new installations and service calls?

3. What kinds of site characteristics and behavioral practices result in the most efficient operation of heat pumps? The least efficient?

4. Do you find that customers modify the control settings for their units?

   a. [IF YES] Do those modified settings make it harder for the system to achieve high energy efficiency goals? How?

   b. [IF YES] Do those modified settings make it harder for the system to achieve comfort goals? How?

5. Do you reconfigure system controls for service or maintenance calls?

   a. [IF YES] How often? IE, on what share/percentage of maintenance calls?

   b. [IF YES] How do you balance comfort and efficiency when configuring or reconfiguring system controls?

6. New York State has proposed aggressive goals for deploying high volumes of heat pumps very quickly (refer them to NYS Clean Heat Statewide Heat Pump Program and landing page (https://saveenergyny.ny.gov/NYScleanheat/ for high level summary. What barriers do you think will make it difficult to achieve these goals?

   a. Do you have any suggestions for how to overcome those barriers?

7. Is there any other feedback you'd like to provide about NYSERDA's heat pump program?

Thank you for answering my questions today.

APPENDIX D. SURVEY/INTERVIEW RESULTS MEMO

In December 2020 DNV (formerly ERS) submitted to NYSERDA a memorandum summarizing results from customer surveys and installer interviews. A copy of the memo is included in this appendix.

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PHASE 1 SURVEY FINDINGS

TO: Tracey DeSimone and Elizabeth Boulton – NYSERDA

FROM: Jennifer Childs, DNV GL Energy Insights, and Kelly O'Connell, ERS

CC: Jon Maxwell, ERS, Bradley Campbell, DNV GL, and Tom Ledyard, DNV GL

RE: NYSERDA Heat Pump Evaluation Phase 1 Survey Findings

Note: **Blue text** indicates content submitted to NYSERDA for review on November 24, 2020.

Objective

The primary objective of this memo is to bring together 151 customer surveys and 24 installer interviews into a single narrative to add context to the observed performance of high-efficiency heat pumps in the NYSERDA program and provide forward-looking recommendations for similar future heat pump initiatives. The NYSERDA heat pump programs have been discontinued, so the conclusions drawn in this memo are focused on understanding the program's past performance, and the recommendations provided are framed prospectively. We often split our pilot results as NYSERDA was much more directly involved in this effort. Specifically, these sites were unique in their general oversight, delivery, upfront M&V, and quality control. The broader air source heat pump (ASHP) and ground source heat pump (GSHP) programs were midstream so many customers might not have been aware they participated in a program at all.

To meet this objective, the interview guide gathered information on three primary areas of interest:

- **Heat pump sales process**, especially contractor perspectives on the conditions that are most conducive and cost-effective for heat pumps.
- **Installation process**, especially the problems encountered, refrigerant material, and controls to optimize heat pump use with other on-site HVAC systems.
- **Operations and maintenance**, especially recurring repair issues including refrigerant leakage.

The web-based customer survey gathered the below information on the heat pumps installed:

- **Current use**, including the installation address, the number of heads, and if it is used for heating and/or cooling.
- **Conditioned space**, including changes in the amount of space heated or cooled with the heat pump vs. the previous system(s).
- **Experience with the heat pump**, including installation, repairs, maintenance, and operational difficulties.
- **Previous cooling and heating equipment**, including the primary heating system fuel type and the current use of the system to supplement the heat pump.
- **Water heating equipment changes**, including fuel used and type installed, whether the heat pump install triggered the need for the installation.

Methods and Sampling

The in-depth telephone interviews with contractors were conducted in June and October of 2020, with an interim period in the summer of 2020 due to the COVID-19 pandemic that resulted in many firms being shut down or otherwise difficult to contact. DNV GL conducted interviews with 24 firms in those two periods. The firms contacted were a subset of contractors with program installations. Contractors were placed into two size categories based on the number of program applications. Table 1, below, summarizes the population and sample. Twenty-four of the 65 contractors (~37%) were successfully interviewed. Twenty-one of 24 installers contacted reported that they install air-source heat pumps (ASHP); 10 reported installing ground-source heat pumps (GSHP), with seven reporting that they install both types of heat pumps.

Table 1. Installer Interview Population and Sample Summary

Size	Population (N)	Sample			
		Total (n)	Install ASHP	Install GSHP	Install Both
Fewer than 5 applications (Group A)	51	14	11	7	4
More than 5 applications (Group B)	14	10	10	3	3
Total	65	24	21	10	7

The customer surveys were web based and completed from December of 2019 through February of 2020. The online survey was an attempted census of the 4,515 participants, so no explicit sample design was created prior to fielding. The population of program activity is summarized in Table 2(below) by equipment type/program, and pre-existing fuel type.

Table 2. Participant Population Summary

Pre-existing Fuel	ASHP	GSHP	Pilot	Total
Electric	247	118	3	368
Natural Gas	3,097	14	13	3,124
Oil	483	98	18	599
Other/Multiple	43	169	8	220
Propane	143	60	1	204
Total	**4,013**	**459**	**43**	**4,515**

Although the study did not use a sample design to target specific customers, a substantial effort was made to ensure reasonable representation among key population characteristics, including heat pump technologies, climate zone, and fuel type saved. As web surveys were completed in the various strata that were defined by these characteristics, ERS made a targeted phone effort to ensure strata with low-response rates were being actively pursued for completion. Through this effort, ERS completed 751 participant surveys.

Once data was collected, ERS post-stratified the population to control for differential response rates along the key sample design dimensions. The ensuing case weights are used to ensure that the characteristics of the respondents reflect the population characteristics (technologies, climate zone, and fuel saved). The final weights are provided in Attachment A of this memo.

Heat Pump Sales Process

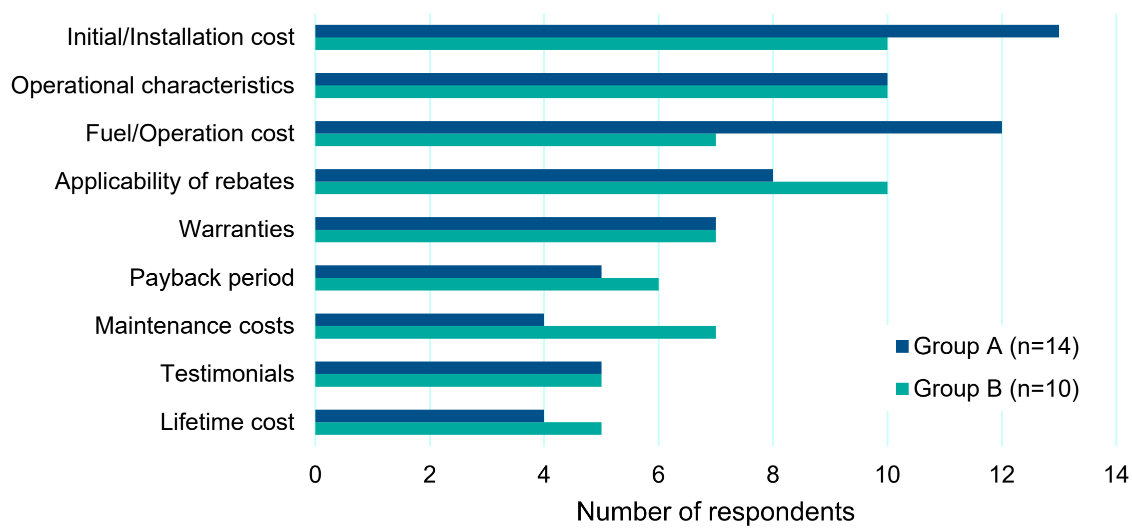
Fifteen of 24 heat pump installers shared their approximate number of annual heat pump installation projects. This ranged from a low of four projects per year to three firms with 500 or 1,000+ estimated annual installations, with an average of approximately 200 heat pump projects per year. The installers with more than five NYSERDA heat pump applications per year (Group B) averaged 296 projects per year and Group A installers (< 5 projects per year) averaged 143 projects per year. While it was not always easy to tell if a company offered natural gas or other fossil fuel-based HVAC options, the data suggests that 11 of the 24 (46%) only offer heat pump technology solutions. This indicates that many contractors are focused on filling the unique needs of the heat pump market.

Table 3. Distribution of Annual Heat Pump Projects

Number of Projects	Number of Installers (n)
25 or fewer	4
26 to 50	6
51 to 100	2
More than 100	3
Total	15

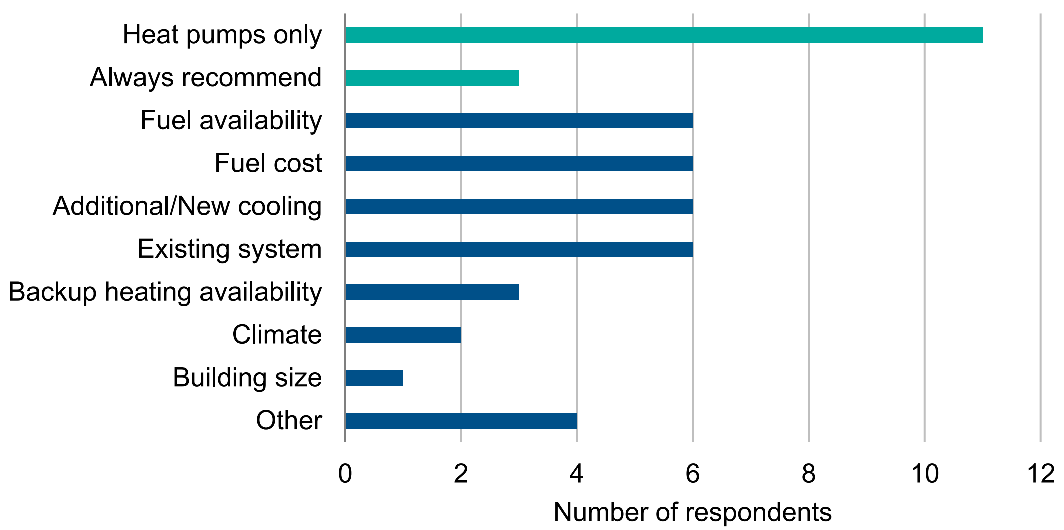
Installers were asked how, if at all, they helped customers decide what technology to install when considering heat pumps. The type of information provided to customers is included in Figure 1, below. Installers reported all information types provided to customers, resulting in multiple responses per installer. The information most frequently provided included installation cost, operational characteristics, fuel cost, and information about rebates or low-cost financing. The high frequency of these responses might be expected, given their importance at the point of sale. Key elements of the sales process include the role of rebates in offsetting high installation costs and conveying the characteristics of a technology that is rapidly evolving in capability and functionality to meet space conditioning. Both groups of installers provide similar levels of each information type to customers. Nearly all Group B installers (> 5 applications) offer information on fuel, operation, and initial installation costs. Less than half of the installers provided lifetime cost information, payback period, and/or maintenance costs. We speculate that, while these are also important sales points, they are more difficult to quantify and explain, and represent future benefits that may not resonate as strong as short-term adoption costs.

Figure 1. Information Regularly Provided to Customers by Installers



Installers were asked the conditions in which they recommend a heat pump over a combustion heating system. Eleven of 24 respondents stated that they install heat pumps exclusively (therefore, always recommend a heat pump over other systems). Three stated that they always recommend heat pumps but have alternative options available. These respondents are shown in the top, teal-shaded bars in Figure 2. The remaining 10 installers recommended heat pumps partially, depending on site-specific conditions, as shown in Figure 2. The analysts did not split out the installer groups in Figure 2 due to the low response rate (n=10) to the base question. It is common to see customer interest in cooling trigger the recommendation for a heat pump unit over a replacement fossil fuel, heating-only system. Recommendations for heat pump technologies are also often made because of fuel cost concerns, and/or the market-driven nature of this technology. Naturally, the configuration of the pre-existing system and alternative HVAC system options drive the fuels saved.

Figure 2. Heat Pump Recommendations: Only, Always, and Site-Specific Conditions



Finally, installers were asked what information influences customers. Figure 3, below, compares installer responses (based on what they believed influences customer decisions) to the information they actually provided to customers. As would be expected, the three pieces of information most frequently reported as influential are also the three most regularly provided to customers. Testimonials were regularly provided by 10 installers, though only four reported them as influential to customer decision-making. It is interesting that initial cost, while first, is not overwhelmingly reported as more influential than other items of information. Lifetime costs are perceived as influential but not regularly provided. Future efforts to promote heat pumps will benefit from understanding customer influences to maximize adoption rates.

Figure 3. Information that Influences Customer Decisions

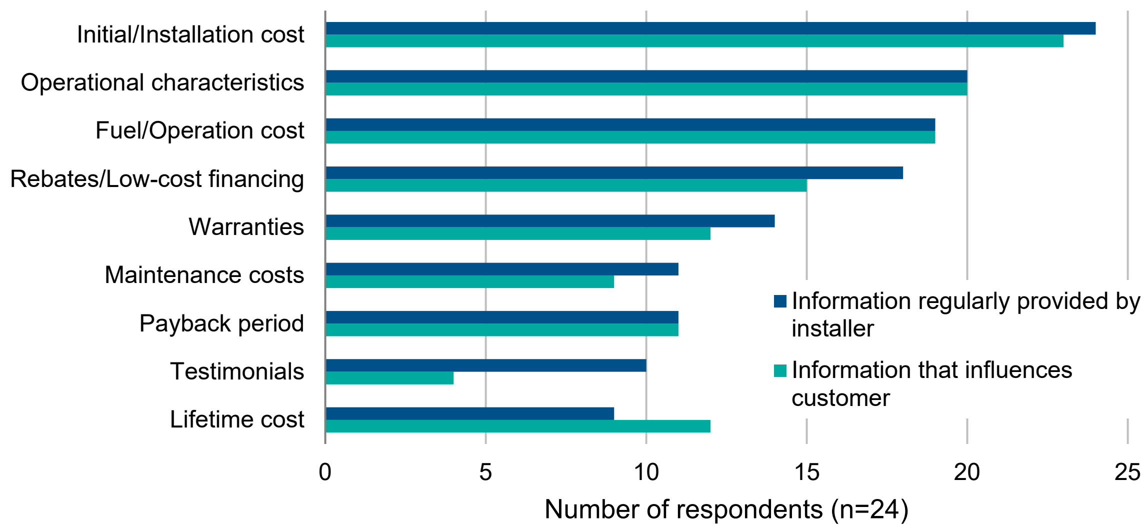


Table 4 shows heat pump installations by type and sector for the customers that responded to the internet survey. The vast majority of the installations are in the residential sector (97%) with the balance effectively in C&I. Performance among the residential installations drives the program impacts. As noted in the impact study, and also evidenced here, there were an insufficient number of non-residential installations to derive specific impacts for that sector.

Table 4. Heat Pump Installations by Type and Sector

Sector	ASHP	GSHP	Pilot	Total	% Total
Residential	3,904	430	43	4,377	97%
Non-residential	109	26	-	135	3%
No response	-	3	-	3	0%
Total	**4,013**	**459**	**43**	**4,515**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

Table 5, below, shows the customer-reported conditions for the installation of heat pumps in the sample. This is provided by heat pump program or equipment type (air source, ground source, and pilot) and nature of the space (existing, new construction, and remodeled/additions). The majority of installations are ASHPs, which represent nearly nine in ten (88.9%) of all units; GSHP represents 10.2%. Most units are installed in an existing space (78.4%), with the balance divided nearly evenly among new construction and remodeled/added spaces. Seventy percent of all installations are ASHPs in existing spaces. As noted in the Phase 1 Billing Analysis Results Memo, this high rate of ASHP installations makes their performance the primary driver of the verified gross savings (VGS) realization rates (RRs). Their installation in spaces with preexisting heating and/or cooling causes impacts among a variety of fuels.

Table 5. Heat Pump Installations by Type and Space

Space Type	ASHP	GSHP	Pilot	Total	% Total
Newly constructed	277	107	–	384	9%
Remodel or addition	432	15	1	448	10%
Existing space	3,175	324	42	3,541	78%
Other	19	6	0	25	1%
Don't know/refused	109	7	0	116	3%
Total	**4,013**	**459**	**43**	**4,515**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

Figure 4, below, shows the number of heads installed per ASHP unit. A significant number of respondents (859) were not sure how many heads were installed, despite the internet survey providing illustrations. Of those who did, 39% had one head, 19% had two, 13% had three, and 29% had more than three. The presence of multiple heads introduces an increased possibility of displacing multiple fuels and changes in customer behavior from previous, more centralized systems.

Figure 4. Number of Installed Heads per Customer (ASHP)

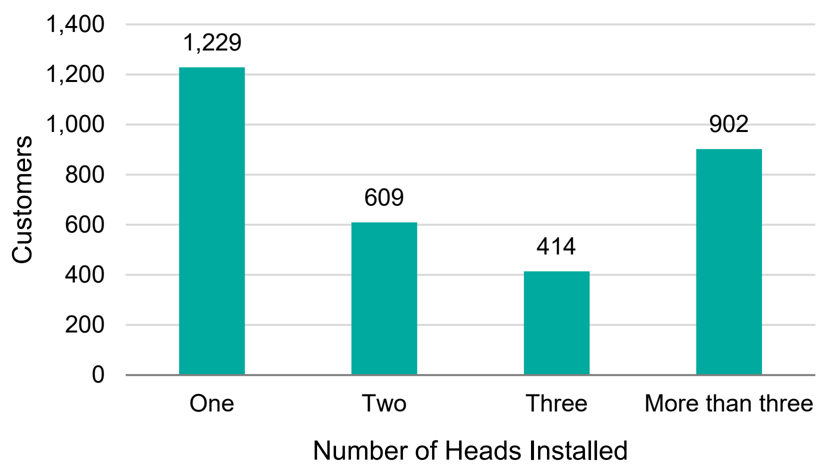


Table 6, below, shows the portion of customers using their heat pump for heating and/or cooling. Over three quarters of respondents said they are using their heat pump for both heating and cooling. Twenty one percent of customers reported using their unit for only heating or only cooling (14.2% and 7.3%, respectively). The billing analysis verified gross savings (VGS) realization rate (RR) for cooling-only use was very low (6%) as opposed to those who used their unit for heating only (VGS RR of 48%) and those that used it for both (VGS RR of 37%).

Table 6. Heat Pump Seasonal Use

Seasonal Use	ASHP	GSHP	Pilot	Total	% Total
Cooling only	643	-	-	643	14%
Heating only	303	25	-	327	7%
Both	2,971	427	43	3,442	76%
Don't know/refused	97	7	-	103	2%
Total	**4,013**	**459**	**43**	**4,515**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

ERS asked respondents whether the space served by the new heat pump was larger or smaller than the space served by the existing system(s). The responses provided in Table 7 do not include units installed in new construction. A total of 4,130 units were installed in spaces that were not new construction. Among that group, 87% reported that the space remained the same size as that served by the previous system and 6.3% reported the space had increased in size. Less than one percent said the space had become smaller.

Table 7. Changes in Space Served by Heat Pump

Space Served	ASHP	GSHP	Pilot	Total	% Total
Larger	232	27	2	261	6%
Same	3,253	312	41	3,606	87%
Smaller	37	0	0	37	1%
Other/don't know	214	12	0	226	6%
Total	**3,736**	**352**	**43**	**4,130**	**100%**
% Total	**90%**	**9%**	**1%**	**100%**	

Table 8 summarizes the amount of change in square feet served by the heat pump unit compared to the previous square footage. For example, among the 261 customers who reported their heat pump serves a larger space than their previous HVAC system, 129 of them increased their space between 0 and 500 square feet, 12 reduced the space between 0 and 500 square feet, etc. Although only 7.2% of respondents reported a change in the size of the space served, the range of square feet added or reduced is wide and highlights the importance of proper sizing techniques. Changes to the space served can also signal a customer's decision-making process on whether to install the heat pump in lieu of the existing system expansion or contraction.

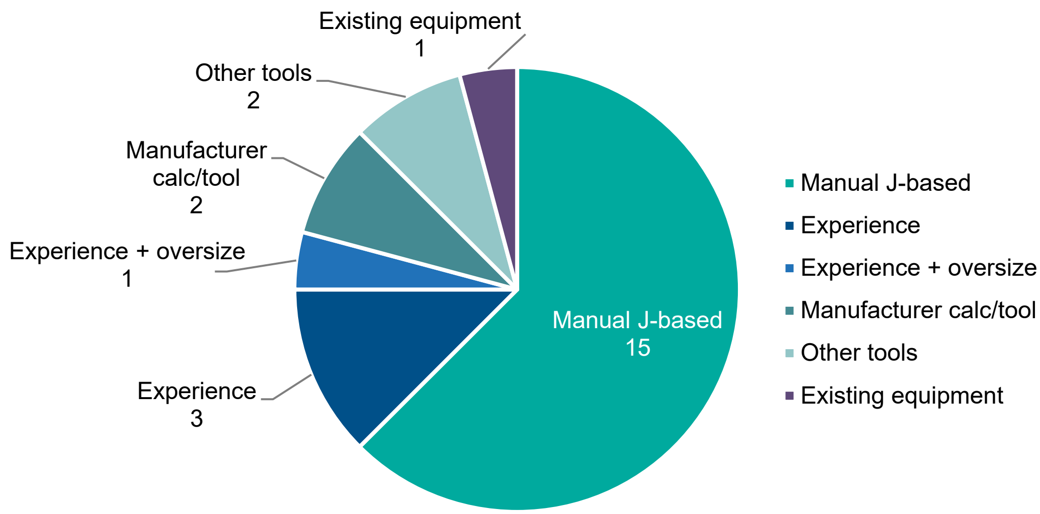
Table 8. Change in Square Feet Served by Heat Pump

Space Size Change	0-500	501-1,000	1,001-2,000	>2,000	Total
Larger	129	83	11	38	261
Smaller	12	7	3	15	37
Total	**141**	**89**	**14**	**54**	**299**

HEAT PUMP INSTALLATION PROCESS

Installers were asked what types of calculations they use to determine system sizing. System sizing is generally done to ensure a necessary amount of heating capacity (as opposed to cooling capacity, which is more of an amenity than a necessity). Figure 5 shows 15 of 24 (63%) installers cited use of Manual J, either directly or folded into another sizing tool. Four out of 10 installers from Group B reported the use of Manual J, while 11 of 14 installers from Group A reported its use. Overall, the next most frequent response was based on four installers that cited "experience" (one separated explanation of sizing based on experience, and explicitly citing oversizing systems as a method of system sizing). Other responses included sizing tools from the manufacturer (2), other tools (2), and based off existing equipment (1). The use of Manual J by 63% of installers is reasonable given the reported use of other satisfactory manufacturer tools. However, the low number of Manual J users among Group B installers makes it clear there is room to increase use of this method among installers who are regular participants in heat pump initiatives. Under-sizing, in particular, can affect the impacts of heat pumps through increased runtimes and higher rates of full operation.

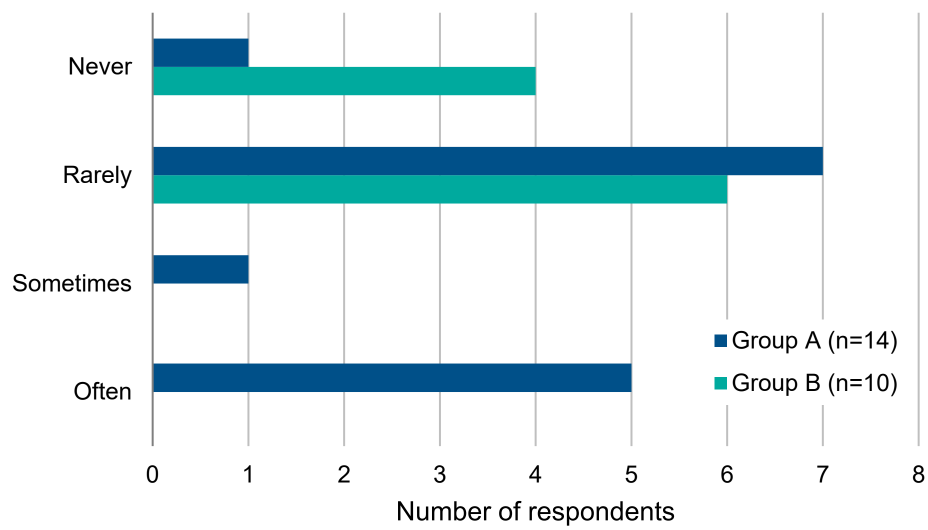
Figure 5. Sizing Calculation Methods



Only five installers indicated that sizing practices differ by equipment type. Two of the five provided further detail on this, with one citing "years of experience" and another indicating it depends on the "system and the space." While the majority of installers did not indicate that sizing varies based on the different types of equipment, several indicated that they do consider additional factors. These factors were all site-dependent, such as site infiltration, building use type (residential/commercial), or condition of existing ductwork. Nine installers indicated that they consider flow sizing, which can be an important factor, as the airflow requirements can be different between an existing system and a new HP unit. Of the remaining 15, three did not provide a response to the question, and four indicated that they tried to stay away from custom work in installations and thus did not explicitly consider flow.

Following system sizing, installers were asked about the installation of controls, specifically those to optimize use of the installed heat pump with secondary heating or cooling sources. Controls of this nature are often considered a key part of realizing savings from a heat pump system. Only five installers claimed to “often” install controls, and one stated they “sometimes” did, which were all among Group A installers. The majority, 18 of 24 installers (75%), indicated they “rarely” or “never” install controls to optimize heat pump and secondary sources, including all Group B installers. In the absence of controls, homeowner training becomes a key part of maximizing heat pump efficiency and use in conjunction with other supplemental systems. The impacts of a heat pump rely on complementary use of the new system with any backup systems still being operated.

Figure 6. Control Installation Frequency



The customer survey also gathered information on the presence of controls to manage the use of the heat pump with the previous primary heating and cooling systems reported to still be in use. This only includes respondents who reported using the heat pump and pre-existing system(s) together. Those who were not asked are in the missing column. Nearly all of the respondents reported they did not know if they had controls or knew they did not have them. Only 7% of respondents who use their previously existing heating systems with their heat pump have controls. A similar low fraction of respondents (2%) who use their previous cooling system with their heat pump have them. This correlates with the contractor results above that show most installers reported installing controls rarely or never.

Table 9. Presence of Controls for Heat Pump and Pre-Existing HVAC System Coordination

Controls Presence	ASHP	GSHP	Pilot	Total	% Total
Heating					
Has control system	146	–	–	146	7%
Does not have control system	1,438	–	21	1,459	72%
Missing	358	48	4	409	20%
Total	**1,941**	**48**	**25**	**2,014**	**100%**
Cooling					
Has Control System	11	–	–	11	2%
Does not have Control System	419	–	3	423	77%
Missing	86	28	2	117	21%
Total	**517**	**28**	**6**	**551**	**100%**

Installers were asked what factors determine if they will or will not install such controls. The following bullets examine these factors according to how often they reported installing them.

Never: Of the five respondents that stated that they never install heat pump controls, four install only air-source heat pumps, and one installs only ground-source. Of the four air-source heat pump installers, they stated that they: tend to only do simple installations (2); do not offer integrated controls (1); and that NYC prevents them from working on boilers, thus preventing the installation of this type of control (1).

Rarely: A wide variety of reasons were cited for rarely installing such controls. Two cited use of brand-specific controls, and many cited a preference (of both installers and customers) to keep installation and use as simple as possible.

Sometimes: One installer stated that they will install these types of controls sometimes, as part of the whole-home assessments they perform.

Often: Those who stated that they often install these types of controls did not provide strong reasons why. Instead, it was simply a part of their normal procedure. Four out of five of these installers stated that they installed ground-source heat pumps, indicating larger and more complex installations than air-source heat pump installations.

Installers were also asked how often they experience installation problems with heat pumps. Twenty-two of 24 indicated they rarely (14) or never (8) experience installation problems. The remaining two responded that they sometimes experience issues, citing manufacturing defect (warranty) issues (1) and customer operation issues where the new system does not operate the same as the replaced system (1).

To what extent new heat pump installations require electrical panel upgrades was of particular interest to this survey. Twenty-two installers provided responses, with 13 of 22 citing never (2) or rarely (11). Eight installers said that panel upgrades were sometimes necessary, and one cited that such upgrades were often needed; the most common reasons were that an upgrade was often necessary on old buildings (urban and rural), or that the existing panel was full.

Cooling Preexisting equipment and Conditions

Customers who have installations in existing spaces and are currently using the heat pump for cooling were asked about the primary equipment they used to cool the space previously. A total of 75% of respondents said their spaces were previously cooled with some type of compressor-based system. An additional 12% of spaces were not cooled but still have a cooling baseline, as participants expressed an intent to start to cool the space with another type of system if not the program heat pump. This leaves 9% of participants that use the systems for cooling as potential load building. While a small percentage, this cohort can significantly reduce program savings.

Room air conditioners were the most frequently displaced technology (59%) with central systems and fans a distant second and third at 10% and 9%, respectively. Twelve percent reported the space was previously uncooled.

Table 10. Previous Cooling System Used to Serve Space Before Heat Pump

Previous Equipment Type	ASHP	GSHP	Pilot	Total	% Total
No cooling equipment	325	55		380	12%
Room air conditioners	1,844	67	27	1,938	59%
Central air conditioner	238	73	9	321	10%
Fans	256	37	1	295	9%
Ductless heat pump	98		4	102	3%
GSHP	12	67		79	2%
ASHP	31	2		33	1%
Evaporative cooler	12			12	<1%
Other	5			5	<1%
Don't Know	67	2		69	<1%
Total	2,888	303	41	3,234	100%
% Total	89%	9%	1%	100%	

Table 11, below, shows the responses of those customers who reported having a previous cooling system in Table 10, above. Those respondents were then asked, if it is still being used to provide cooling and how frequently the system is used. Overall, about 19% of respondents indicated they are still using their previous system with about two-thirds of that group reporting it is used infrequently. This low rate of combined use suggests that there is limited opportunity for controls to coordinate the heat pump system cooling operation with that of other home cooling systems. It also suggests that the inefficiency that accompanies dual-system use is not a substantial factor in heat pump cooling season savings.

Table 11. Current Use of Previous Cooling System

Cooling System Use	ASHP	GSHP	Pilot	Total	% Total
Previous system not used	2,064	222	36	2,323	81%
Previous system used frequently	161	8		170	6%
Previous system used infrequently	339	18	6	363	13%
Total	**2,565**	**248**	**42**	**2,855**	**100%**
% Total	**90%**	**9%**	**1%**	**100%**	

Customers with a pre-existing cooling system (not including fans) who are now using their heat pump for cooling were asked if the space served had increased or decreased. Roughly 25% reported that it provides cooling to more space than the previous system, while 5% reported it serves less space. One possible reason for this is that customers are taking advantage of the ability to place heads in a home that allows more than the previous space to be cooled. Of all of the respondents, the largest group consisted of those who used the heat pump for the same space as the previous space, with over two-thirds reporting this to be the case.

Table 12. Changes in Cooling Space Size Served by the Heat Pump vs. Previous System

Cooling Space Change	ASHP	GSHP	Pilot	Total	% Total
More space	560	56	22	638	25%
About the same amount of space	1,600	150	19	1,768	69%
Less space	119	2		121	5%
Other	30	4		33	1%
Total	**2,309**	**211**	**41**	**2,561**	**100%**
% Total	**90%**	**8%**	**2%**	**100%**	

This same group, customers with a pre-existing cooling system (not including fans) who are now using their heat pump for cooling, were then asked if they are keeping the temperature cooler, warmer, or the same *in the summer*. The result was a near even split between those that responded they kept the temperature about the same (48%) and those that kept it colder (44%). This question was followed up by asking those reporting a change how many degrees warmer/cooler they kept the temperature with the new heat pump. On average, both groups reported a change of approximately 6 degrees in their respective directions.

Table 13. Changes in Summer Temperature

Summer Temperature Behavior	Program					Reported Change (°F)		
	ASHP	GSHP	Pilot	Total	% Total	Total	Average	Max
Warmer	91	5		96	4%	69	+6.1	+15
About the same	1,090	130	13	1,233	48%	-	-	-
Cooler	1,040	71	28	1,139	44%	621	-6.3	-25
Don't know/ no response	87	6		93	3%	-	-	-
Total	**2,309**	**211**	**41**	**2,561**	**100%**	**690**	**703**	**-25**
% Total	**90%**	**8%**	**2%**	**100%**				

An additional subset of customers provided their temperature set point. This is believed to be a misunderstanding of the question. This sub group all responded that they now set their summer temperature cooler, to an average of just below 73 degrees in the summer.

Table 14. Summer Temperature

Degrees	ASHP	GSHP	Pilot	Total	% Total
80	3			3	2%
78			4	4	3%
75	37			37	27%
73	25	2		27	20%
72	25			25	18%
70	40			40	30%
Total	**131**	**2**	**4**	**136**	**100%**
% Total	**96%**	**1%**	**3%**	**100%**	

HEATING PREEXISTING EQUIPMENT AND CONDITIONS

Customers who have installations in existing spaces and are currently using the heat pump for heating were asked about the primary equipment used to heat the space previously. Central furnaces or boilers was the most frequently displaced technology (71%) with central heat pumps and wood stoves a distant second and third at 7% and 5%, respectively. Ten percent reported the space was previously unheated.

The compact nature of heat pumps and their ease of installation make them flexible systems to meet house heating and cooling needs. However, this flexibility can lead to unit installations that displace all manner of pre-existing systems. To the extent the pre-existing heating system represents a savings baseline, these results shows a diverse set of fuel impacts, including the potential for electric load building.

Table 15 Previous Heating System Used to Serve Space before Heat Pump

System Type	ASHP	GSHP	Pilot	Total	% Total
No heating equipment	264	21	3	288	10%
Central furnace/boiler	1,827	180	37	2,043	71%
Central heat pump	116	83		199	7%
Wood stove	113	39	–	152	5%
Room plug-in/space heaters	16	–	–	16	1%
Unit heater (all fuels)	38	3	–	41	1%
Fireplace	4	2	–	6	0%
Other	126	–	2	128	4%
Don't know	5	–	–	5	<1%
Total	**2,509**	**326**		**2,878**	**100%**
% Total	**87%**	**11%**	**1%**	**100%**	

Those who responded that their heat pump replaced a central furnace or boiler, unit heater, fireplace, or "other" heating equipment were asked what fuel the previous equipment used. Natural gas was the most common response, covering nearly two-thirds (60%) of these units, followed by heating oil. This level of gas baseline does not produce the carbon impacts derived from the program assumed baselines of electric resistance, fuel oil, wood, or kerosene. All other fuels comprised only a combined 10% of fuel sources. Insofar as heat pumps are a clean heating source, the substantial MMBtu offset of heating oil can be significant, although it is a far less frequent baseline than natural gas.

Table 16. Fuel of Previous Heating Fuel

Previous Heating Fuel	ASHP	GSHP	Pilot	Total	% Total
Natural gas	1,276	38	15	1,276	60%
Heating oil	558	80	20	558	30%
Propane	105	49	3	105	7%
Wood/biomass	4	8		4	1%
Other	51	8		59	3%
Total	**1,995**	**184**	**39**	**1,995**	**100%**
% Total	**90%**	**8%**	**2%**	**100%**	

Table 17 shows the responses of those customers who reported having a previous heating system above in Table 16 whether it is still being used to provide heating, and if so, how frequently. This question was only asked if the heat pump is being used to heat an existing space that was previously heated. Overall, about 72% of respondents indicated that they are still using their previous system, with about two-thirds of that group reporting it is used frequently.

These are much higher rates than those seen in the use of pre-existing cooling systems with the heat pump. This high rate of combined use suggests that there is a significant opportunity for controls to coordinate the heat pump system operation with that of other home heating systems. Improper use of the heat pump with existing systems use can greatly affect the cost and energy savings experienced by customers.

Table 17. Current Use of Previous Heating System

Previous System Use	ASHP	GSHP	Pilot	Total	% Total
Previous system not used	504	268	17	789	28%
Previous system used frequently	1,258	13	4	1,275	46%
Previous system used infrequently	683	35	21	739	26%
Total	**2,445**	**316**	**42**	**2,802**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

Those customers who used their previous system with their ductless mini split were asked how often both systems are in use. Most respondents (59%) reported that they are used together less than 25% of the time, while a quarter of respondents reported that they use them together between 25% and 50% of the time. This suggests that these units are used in tandem during particularly cold periods.

Table 18. Percent of Time Heat Pump Is Used with Previous Heating System

Percent Time	ASHP	Total	% Total
0%	4	4	3%
<25%	89	89	59%
25%-50%	37	37	25%
51%-75%	12	12	8%
76%-100%	4	4	2%
100%	3	3	2%
Total	**150**	**150**	**100%**
% Total	**100%**	**100%**	

Customers with a pre-existing heating system that are now using their heat pump for heating were asked if the heat pump was used to heat the same amount of space in their home/business as the previous equipment, less space, or more space. Roughly 8% reported it provides heating to more space than the previous system, while 21% reported it serves less space (i.e. fewer square feet). Of respondents, the largest group consisted of those who used the heat pump for the same space as the previous space, with over two-thirds reporting this to be the case. In comparison to heat pumps used for cooling, the shares of those using more space and less space are nearly inversed between the two; more space conditioning accounts for 25% of cooling and only 8% of heating, while less space conditioning accounts for a mere 5% of cooling but 21% of heating. As it seems unlikely that homeowners are shrinking the size of their homes, this indicates that at least one-fifth (21%) of those who use the heat pump for heating in existing homes are using it for only a portion of the conditioned space, not the entire home.

Table 19. Changes in Heating Space Size Served by the Heat Pump vs. Previous System

Heating Space Change	ASHP	GSHP	Pilot	Total	% Total
More space	172	41	10	224	8%
About the same amount of space	1,603	276	28	1,908	69%
Less space	571		3	574	21%
Other	43			43	2%
Don't know	16			16	1%
Total	**2,404**	**318**	**42**	**2,764**	**100%**
% Total	**87%**	**11%**	**2%**	**100%**	

Heat Pump Operations and Maintenance

The survey asked installers about their experiences with operations and maintenance of heat pumps and heat pump systems. First, installers were asked for any common issues that require post-installation service callbacks. The majority (13/24) stated that such issues were uncommon or very rare. The remainder generally indicated that any service callbacks were infrequent, but included small issues such as thermostat settings, regular maintenance, or refrigerant recharge. Two contractors noted that they get calls that units are not providing sufficient heat in cold weather, and three identified coil leakage or coil freezing.

All installers were asked how often they need to perform service calls for refrigerant, either due to leakage or needing a recharge. Five stated that they never have these types of calls, and 17 indicated that these calls were rare. Only one indicated that this happened sometimes. When asked how that compares to traditional systems, the one who said that it happened sometimes stated, "maybe 5% compared to traditional systems." Finally, installers were asked about the most common refrigerant used in new installations and service calls; 100% (23/23) identified R-410a.

Customers were asked about problems during or after heat pump installation. Eleven percent of respondents (458) reported such problems in Table 20. Table 21, below it, presents the nature of those issues, though many customers were not able to provide a response to this question (352). No single issue involved a significant number of individuals that were diverse in nature. Those who were able to recall cited outdoor unit vibrations sometimes requiring repositioning (22%), needing extra time to understand the unit (16%), and receiving error messages delivered through the system controls. The nature and rate of customer-reported installation issues observed does not suggest any systematic issues of concern.

Table 20. Issues Encountered During or After Heat Pump Installation

Issue Encountered	ASHP	GSHP	Pilot	Total	% Total
Yes	313	125	18	458	11%
No	3,547	327	24	3,899	89%
Total	**3,860**	**452**	**42**	**4,357**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

Table 21. Customer-Reported Heat Pump Issues

Issue Encountered	ASHP	GSHP	Pilot	Total	% Total
Vibrations	23			23	22%
Extra home work after install	12	4		17	16%
Error messages	4	10	1	15	14%
User training	12			12	12%
Contractor issue	3	2		5	5%
Controls changes required		4		4	4%
Inadequate heat	4			4	3%
Schedule		4		4	4%
Other	16	6		22	21%
Total	**74**	**31**	**1**	**106**	**100%**
% Total	**70%**	**29%**	**1%**	**100%**	

When asked if the heat pump has needed any repairs or replacement of parts since being installed, 88% of participants responded that it had not. A small number indicated that the air filter had been replaced – those responses were included as “No,” as they are basic, standard operation maintenance and do not indicate a true replacement.

Table 22. Reported Rate of Heat Pump Repairs Needed

Repairs Needed	ASHP	GSHP	Pilot	Total	% Total
No	3,491	311	34	3,836	88%
Yes	354	136	9	499	12%
Total	**3,845**	**447**	**43**	**4,336**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

While not everyone provided the specific repair needed, respondents representing 280 heat pump customers did. A small number (4%) said they required the installation of a full new unit due to failure of the original unit. There were four primary repair types mentioned. These included:

- **Mechanical.** Sixteen percent of repairs cited were mechanical in nature, including fan motors, pressure valves, heating coil, and related connections.

- **Electrical.** Twelve percent of repairs cited were electrical in nature, including circuit and mother boards, Wi-Fi sensors, thermostat, and general wiring issues.
- **Piping/Leaks.** Ten percent of repairs cited were related to refrigerant, condensate, or other unit piping, including leaks, purging, and expansion issues.
- **Installation.** Eight percent of respondents reported issues stemming from the initial installation, including the need for a condensate line, unlevel installation, and improper connections.

Only eight installers responded when asked about the characteristics or behavioral practices that result in the most efficient or least efficient heat pump operation; among these responses, there were a couple of themes. Many respondents stated operating units at the "right," "reasonable," or "constant" temperature enables unit efficiency. Three reported that rightsizing is important to optimize efficiency. Inefficient or less efficient practices included performing temperature setbacks, frequent temperature changes, poor home characteristics (envelope, large windows, etc.), and customers that are not well-educated on how to properly use heat pumps.

Customer behavior related to heat pump temperature setpoints is a key determinant in realizing unit efficiency and savings.

Installers were asked if they find that customers modify control setting for their units; only eight said yes. Of those eight, six believed that those modified settings make it harder to achieve high energy-efficiency goals. Only one believed that these modified settings make it harder to achieve comfort goals.

Fourteen of 23 installers identified system control reconfiguration as an item performed for service or maintenance; however, only two of these installers identified this as something done "sometimes," with the rest stating it is done "rarely."

Domestic Hot Water Systems

ERS asked a battery of questions about participants' domestic hot water (DHW) systems. The first was the type of hot water system currently installed. Nearly three-quarters of respondents have a tank-style water heater. Tankless and heat pump water heaters are being used in 11% and 9% of homes, respectively.

Table 23. Current Water Heater Equipment

DHW Equipment Type	ASHP	GSHP	Pilot	Total	% Total
Tank-style	2,737	236	35	3,007	73%
Tankless	398	33		431	11%
Heat-pump water heater	234	143	5	382	9%
Side-arm	196	8		204	5%
Geo pre-heat tank		20		20	<1%
Don't know	3	2		5	<1%
Other	38	6	3	47	1%
Total	**3,605**	**448**	**43**	**4,096**	**100%**
% Total	**88%**	**11%**	**1%**	**100%**	

Table 24 shows the hot water heater fuel types used. Natural gas (57%) and electricity (26%) combined are used in 83% of hot water heaters. Oil and propane are used far less at 7% and 6%, respectively.

Table 14. Water Heater Fuels Used

Fuel	ASHP	GSHP	Pilot	Total	% Total
Natural gas	2,365	24	16	2,404	57%
Electricity	711	361	15	1,087	26%
Heating oil	294	5	4	303	7%
Propane	231	38	3	272	6%
Other fuel (please explain)	23	10	3	36	1%
Same fuel as boiler	48	5		53	1%
Solar	32	10	1	43	1%
Total	**3,704**	**452**	**43**	**4,199**	**100%**
% Total	88%	11%	1%	100%	

Sometimes a heating system also provides hot water for a home. When such a system is replaced with a heat pump, a new hot water system is necessary. Table 25 shows that around 10% of respondents needed a hot water installation due to the switch to a heat pump. This included nearly half of respondents who installed a GSHP. We suspect this is due to the expectation among people who install GSHP that the system will cover all of the space heating and cooling needs, whereas people who install mini splits or other ASHPs will tend to keep a boiler in-place as a backup. Consequently, if the boiler remains, the DHW system is also likely to remain in use.

Table 25. Hot Water Installations Due to Heat Pump

DHW System Needed	ASHP	GSHP	Pilot	Total	% Total
No	3,615	228	33	3,876	0.9
Yes	200	206	10	416	0.1
Total	**3,815**	**434**	**43**	**4,292**	**100%**
% Total	**89%**	**10%**	**1%**	**100%**	

Table 26 shows the type of how water system added. Tank style systems were installed 57% of the time, while heat pump water heaters were installed 26% of the time. This is a high rate of heat pump water installations, likely reflecting the predisposition of individuals who install efficient space conditioning systems to similarly install efficient domestic hot water systems.

Table 26. Added Hot Water System Type

System Type	ASHP	GSHP	Pilot	Total	% Total
Tank-style	109	124	5	238	57%
A heat pump water heater	45	61	4	110	26%
Tankless ("on demand') electric	32	4		36	9%
Side-arm (space heating boiler heats water also)	12	2		14	3%
Geo pre-heat tank-style		6	1	7	2%
Other water heater types (please explain)	5	6		11	3%
Total	**204**	**202**	**10**	**416**	**100%**
% Total	**49%**	**49%**	**2%**	**100%**	

Conclusions

Heat pumps are a rapidly evolving technology with a sales model that is dependent on contractor and installer promotion in the marketplace and customers as the final decision maker of where they are installed and how they are used. Gathering both perspectives is key to understanding how units are performing relative to design and program expectations.

- **Contractors and installers.** While there are several ways in which a customer might become interested in heat pump technology, the path to installation typically goes through a contractor specification, recommendation, and installation funnel. The program has engaged a range of contractor sizes who provide these services, including a substantial subset dedicated exclusively to heat pump installations.
- **Program participants.** In their role of final decision maker and user of the installed heat pumps, participants are critical to understanding program baselines, unit operation, and usage behaviors.

Some key findings include:

Customers are adding cooling comfort to their lifestyle. This study observed 25% of spaces with a program heat pump installed were adding cooling to previously uncooled space. For the 75% installed in spaces previously cooled with some type of compressor-based system, nearly four in every ten respondents in this study reported that they had decreased their cooling setpoint from the previous system, and the decrease was significant, an average of ~6 degrees. This change in temperature is a significant addition of cooling comfort with a clear ability to offset heat pump impacts.

The heating baseline is likely producing much less carbon savings than assumed. The program assumes that the new heat pumps are producing emission savings based on the displacement of electric resistance, fuel oil, kerosene, and wood. We estimate that roughly 60% of units displaced heating systems that used natural gas, 30% displaced oil, and 8% displaced a combination of propane and wood. This difference in assumed and observed fuel displacement rates will provide a poorer emissions efficiency than planned.

Contractors use sizing tools, but there is room for improvement. Rightsizing is a point of emphasis in New York's energy code and heat pump programs. Rightsizing maximizes savings. Installers were found to use fairly standard means of sizing, usually Manual J (63%, including three of the four largest contractors) or manufacturer/industry tools (17%). Others rely on experience, pre-existing equipment size, or other tools. This leaves room for improvements, which could be a point of emphasis in contractor engagement.

Most customers continue to use their previous heating system with their heat pump. Overall, about 72% of respondents who use their heat pump in a previously heated space report they still using the previous system, with about two-thirds of that group reporting it is used frequently.

Interactive controls are an underused tool. A lack of controls communications between heat pumps (and other systems that serve the same space) can significantly reduce savings due to redundant operation that is not complementary. Installers reported that controls are infrequently installed; only one fifth reported they often installed them, and two-thirds reported they rarely or never did. This is despite a moderate number of installers acknowledging that (in the absence of controls) customer behavior with the heat pump temperature setpoints is a key determinant in realizing unit efficiency and savings. New York's heat pump program administrators may want to research barriers to promotion and work with contractors to increase installations through training, targeted controls incentives, or other mechanisms.

Persistence factors are promising. Maintenance issues and callbacks were reported to be infrequent. Loss of refrigerant charge was particularly rare, which bodes well for persistence of savings as a function of this factor.

Contractors are heat pump allies. The heat pump installers engaged in the program appear to be strong allies in the pursuit of greater adoption of heat pump technologies. Many only install heat pumps and all are equipped to recommend them depending on conditions experienced in the field. Among the inquires made in this effort, most signs indicate they can continue to be relied on as a valuable part of encouraging heat pumps in the market and a key element of making improvements to assist in realizing their impacts.

RECOMMENDATIONS

The heat pump program evaluated in this study is no longer in operation. The recommendations provided below are appropriate for consideration prior to initiating efforts of a similar nature in the future. Naturally, goals and delivery methods of future programs may differ from those in place for the program period evaluated here. These recommendations may require re-contextualizing to properly inform the design of those future programs.

Recommendation 1. The observation of nearly three-quarters of participants using pre-existing systems to meet heating needs suggests different savings input assumptions will be required in future programs. We recommend that the planning of future initiatives considers more frequent partial heating displacement scenarios than are currently assumed.

Recommendation 2. The observation that natural gas systems are often displaced by program heat pumps leads to concern that installed units are not producing all intended program energy or emissions benefits. We recommend that future heat pump programs either prohibit the displacement of pre-existing natural gas heating systems or acknowledge their presence in program planning and energy and emissions savings claims.

Recommendation 3. ERS recommends that future programs either highly encourage or require the installation of controls to manage heat pump use with pre-existing heating systems. An enhanced incentive for interactive controls is one possible mechanism. There may be limitations to the ability of controls on older pre-existing systems that will need to be acknowledged in such an effort.

Recommendation 4. ERS recommends that future programs consider requiring the use of either Manual J or manufacturer sizing tools to ensure installed heat pumps are not over or undersized. This is important given the increases and decreases of conditioned space often accompanying heat pump installation. It also aligns with New York state policy. An option to exclude the requirement from partial displacement retrofit applications might be appropriate.

Attachment A: Final Customer Response Weighting

Program	Climate Zone	Primary Heating Fuel	Population	Sample	Weight
ASHP	4	Electric	41	9	4.56
		Natural Gas	2,844	228	12.47
		Oil	61	12	5.08
		Propane	5	2	2.50
		Solar	2	1	2.00
	5	Electric	88	19	4.63
		Natural Gas	165	15	11.00
		Oil	116	37	3.14
		Propane	33	11	3.00
		Solar	4	3	1.33
		Wood/Wood Pellets	8	3	2.67
	6	Electric	118	27	4.37
		Natural Gas	89	18	4.94
		Oil	306	87	3.52
		Propane	105	31	3.39
		Solar	4	2	2.00
		Wood/Wood Pellets	24	5	4.80
GSHP	4	Electric	5	3	1.67
		Oil	1	1	1.00
		Other	6	1	6.00
	5	Electric	73	36	2.03
		Natural gas	9	3	3.00
		Oil	66	39	1.69
		Other	113	45	2.51
		Propane	41	22	1.86
		Wood	5	2	2.50
	6	Electric	40	20	2.00
		Natural gas	5	3	1.67
		Oil	31	16	1.94
		Other	40	18	2.22
		Propane	19	9	2.11
		Wood	5	3	1.67
Downstate Pilot	4	Gas	8	4	2.00
		Oil	7	2	3.50
Hudson Valley Pilot	All	All	17	5	3.40
Long Island Pilot	4	Unknown	1	1	1.00
		Gas	2	2	1.00
		Oil	8	6	1.33

APPENDIX E. PHASE 1 BILLING ANALYSIS MEMO

DNV (formerly ERS) submitted to NYSERDA a memorandum summarizing the impact results of Phase 1 premise-level consumption analysis on April 17, 2020. A copy of the memo is included in this appendix.

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MEMORANDUM

DATE: Revised November 18, 2020 (Original: April 17, 2020)

TO: Tracey DeSimone and Elizabeth Boulton – NYSERDA

FROM: Kelly O'Connell – ERS

CC: Jon Maxwell and Patrick Hewlett – ERS, Jennifer Childs – DNV GL

RE: NYSERDA Heat Pump Evaluation Phase 1 Billing Analysis Results

This memo presents the methodology and results of the Phase 1 Billing Analysis for the NYSERDA Heat Pump Impact Evaluation.

1 Program Background and Evaluation Objectives

This evaluation study assesses the performance and energy impacts of ductless mini-split and centrally ducted air-source heat pumps (ASHPs), and ground-source heat pumps (GSHPs) incentivized by three NYSERDA initiatives through 2018: Underutilized Products (ASHP), Heat Pumps and Solar Thermal (GSHP), and the Heat Pump Pilot Projects Demonstration. The impact evaluation is divided into two phases corresponding to the objectives identified in Table 1-1.

Table 1-1. NYSERDA Heat Pump Impact Evaluation Objectives by Phase

Objective	Phase 1	Phase 2
Evaluate annual gross energy impacts of ASHPs and GSHPs	X	X
Establish appropriate baseline conditions	X	X
Characterize seasonal usage of ASHPs and GSHPs	X	X
Assess displacement versus replacement	X	X
Characterize and document HP control systems and usage patterns	X	X
Characterize equipment issues that impact performance	X	X
Collect information on refrigerant		X
Confirm and refine billing analysis through seasonal on-site metering		X

This memo addresses Phase 1 methods and results that achieve the following objectives:

- **Preliminary evaluation of annual gross energy impacts of ASHPs and GSHPs.** Through the billing analysis methodologies described in Section 2, Phase 1 quantifies the energy impacts among electric, natural gas, fuel oil, and propane fuel sources. The results will be updated later based on Phase 2 on-site metering.
- **Establish appropriate baseline conditions.** Surveys of participants provided context on pre- and post-installation conditions at the customer facility or residence in order to confirm pre-project bills as representative of baseline or to inform a modeled baseline.
- **Characterize seasonal usage of ASHPs and GSHPs.** The billing analysis quantified energy impacts during the heating season, cooling season, and swing seasons.
- **Assess displacement versus replacement, control systems, and usage patterns.** Participant surveys provided additional context on whether the heat pumps supplemented or replaced existing HVAC systems and how each system operates.
- **Characterize equipment issues that impact performance.** To the extent possible with analysis of billing data and participant survey responses, evaluators identified reasons for savings deviation between evaluated and reported.

A separate memo addresses survey research findings unrelated to the billing analysis.

2 Methodology

This section describes the methods applied to collect the data and to develop the Phase 1 billing analysis.

2.1 Customer Surveys

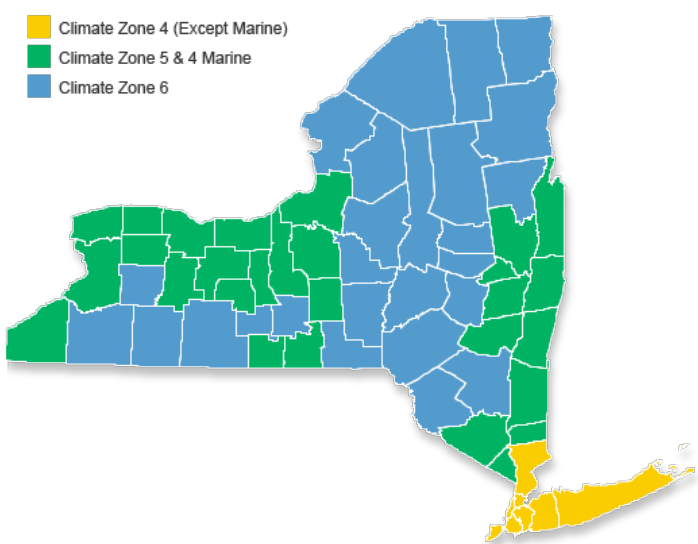
The ERS team conducted a Qualtrics-based mixed-mode survey to collect data on installed heat pump characteristics and use patterns, customer demographics, and utility account information. The ERS team attempted a census by inviting all 4,515 customers either via email or letter. APPRISE, a computer-assisted telephone interviewing (CATI) firm, provided CATI services to follow up with customers in segments with low response rates. The survey responses provide a more in-depth understanding of how the heat pumps are being used and how much they are displacing heating and cooling loads served by existing HVAC equipment. Additionally, the survey provided key participation paths to both phases of the evaluation. For Phase 1, the survey collected customer authorizations to request utility and delivered fuel account information. The survey also introduced Phase 2 of the study to respondents and served to soft-recruit future participation in on-site monitoring. After initial data cleaning to remove incomplete and duplicate responses, the survey received 775 complete responses, with 448 agreeing to provide utility data authorization. The separate survey results memo describes the survey method in more detail.

2.2 Sample Design

While a census of the population was attempted with the customer survey, nonresponse was expected, and the team identified specific completion targets for each technology and climate zone stratum shown in Table 2-1 based on both phases' objectives. Incentives were offered for both survey completion and agreeing to billing data releases to increase response rates and decrease possibility of nonresponse bias. Respondents that only completed the survey questions received a $15 incentive and respondents that also provided billing data authorization received a $50 total incentive. The survey achieved completion rates exceeding initial assumptions. Furthermore, of those who completed the survey, upwards of 75% agreed to be contacted to have metering equipment installed on-site and/or to share their billing information.

Table 2-1 presents the stratified population, counts of survey respondents, counts of respondents providing billing data authorization, and resulting sites included in the billing population, after data cleaning and attrition, which is discussed more in Section 2.4. ERS stratified the population by heat pump type, building type, and climate zone. All ASHPs were installed in residential buildings. Because ASHP unit type was not tracked it was determined based on model number look-ups. Figure 2-1 provides a breakdown of the climate zones by county. Analysts tested different filtering criteria prior to analysis, as is described in Section 2.4.2. The larger font numbers in the Sample column cells indicate the sample size with the recommended moderate filtering criteria. The smaller fonts show the ranges of sample sizes with more and less strict criteria.

Figure 2-1. New York State Climate Zones by County



Source: energystar.gov

Please note that about 20 sites were removed from the analysis population, per NYSERDA's request, because they replaced existing GSHP systems with new GSHP systems. The removal of these sites did not change the overall realization rates of the study.

Table 2-1. Phase 1 Stratified Population

Tech.	Equip. Type	Climate Zone	Sector	Population (N)	Survey Resp.	Authorizing Resp.	Sample (n)	Expansion Weight
ASHP	Centrally Ducted	All	All[1]	10	7	4	3 2 - 3	3 5 - 3
ASHP	Ductless Mini-split	4	All[1]	2,967	276	102	30 19 - 52	98 154 - 56
ASHP	Ductless Mini-split	5	All[1]	412	89	63	36 24 - 50	11 17 - 8
ASHP	Ductless Mini-split	6	All[1]	654	171	124	58 45 - 86	11 14 - 7
ASHP	Ductless Mini-split	Total	Total	4,033	536	289	124 88 - 188	-
ASHP	Total			4,043	543	293	127 90 - 191	-
GSHP[2]	GSHP	4	Non-Residential	2	1	1	3 3 - 3	3 3 - 3
			Residential	21	13	7		
		5	Non-Residential	8	6	5		
GSHP	GSHP	5	Residential	299	141	122	61 55 - 77	5 5 - 4
GSHP[3]	GSHP	6	All	140	69	58	26 22 - 34	5 6 - 4
GSHP	Total			470	230	193	90 80 - 114	-
Total				4,513	773	486	217 170 - 305	-

1. ASHP is not stratified by sector because all ASHP installations were residential.
2. All climate zone 4 and climate zone 5 non-residential GSHP sites were collapsed into a single stratum due to low sample counts. No residential zone 4 GSHP sites were included in the final analysis sample because neither of the two sites in the population met the final analysis criteria.
3. No non-residential zone 6 GSHP sites were included in the final analysis sample because none of the nine sites in the population met the final analysis criteria, so the zone 6 GSHP sector strata were collapsed.

For sample design details, please refer to the "Sample Design Approach for NYSERDA Heat Pump Impact Evaluation" memo, dated February 18, 2020.

2.3 Data Requests

After cleaning and processing the customer survey data, the ERS team compiled the utility data authorizations for data requests. The team prepared individual data requests for each of the investor-owned utilities (IOUs) for both electric and gas accounts, where applicable. When requested, the team also provided the executed authorization forms for proof of customer agreement. Billing data was received from all utilities in a timely manner in spreadsheet format for direct integration into the data processing. The evaluation team received data from Con Edison, Orange & Rockland, Central Hudson, National Grid, National Fuel, NYSEG, RG&E, and PSEG Long Island.

The evaluation team also attempted to collect fuel delivery records for all customers who provided supplier and/or account information (not including wood/biomass users). With support from APPRISE, the team successfully collected delivery records for 55% of the customers. The evaluation team assessed the potential for offering incentives to the fuel suppliers for providing data but determined that they were not needed and likely would not notably increase participation rates. Table 2-2 illustrates the fuel supplier data collection efforts.

Table 2-2. Fuel Supplier Data Collection

	Fuel Companies		Customers	
Status	Total Companies	Percent of Companies	Total Customers	Percent of Customers
Data received	45	61%	88	55%
Data request initiated, but dealer did not follow through	8	11%	25	16%
Dealer refused to provide data	10	14%	15	9%
Dealer not reached/unresponsive	8	11%	28	18%
Reports no deliveries for requested customers	3	4%	3	2%
Total	**74**	**100%**	**159**	**100%**

2.4 Billing Analysis

Upon receipt of pre- and post-installation monthly and bimonthly utility billing data from NYSERDA and irregularly supplied unregulated fuel data from dealers, the analysts standardized the data format, cleaned the periodic energy use readings, and associated each with relevant weather. After further cleaning at the site level, the team attempted pre- and post-installation regression analysis for each. The third and final step of cleaning was based on the team's review of regression results.

The team developed billing data-based analyses on linear regressions with variable base degree-day consideration for heating and cooling. For sites with electric heating and cooling, this means a 5-parameter change point model. For fossil fuels and sites with electric heating or cooling but not both, 3-point models apply. See Attachment A2 for details. Once the relationship between home energy use and outside temperature was developed using recent-year use and weather data, annual energy use was normalized for long-term average expected performance using typical meteorological weather data for the last ten years. For sites where pre-installation data and regressions were either irrelevant (new construction, replace on failure) or incomplete, engineering relationships and post-installation consumption data was used to estimate pre-installation use and savings.

Attachment A describes the cleaning and analysis process in detail.

2.4.1 Billing Analysis Attrition

As described in Attachment A, the ERS team reviewed and cleaned each site based on the requirements presented in Table 2-3. After receiving 488 customer data authorizations through the survey, a range of 160 – 290 sites were eligible to be analyzed via billing analysis depending upon the filtering criteria applied, which represents a 34% - 59% attrition rate. The survey and customer data authorization process was the greatest limiting factor in the analysis population size. Downstate program participation was high, nearly 75% of the participants compared to 43% of the population, but their response rates were low, 25% of the sample.

Table 2-3. Billing Analysis Attrition Summary

Analysis Requirement	Sites Retained	Sites Removed	Attrition Reason
Total population	**4,513**	**-**	**N/A**
Customer provided data access authorization	488	4,025	0 – No survey response or authorization not provided
Customer provided utility and/or fuel account numbers	481	7	1 –Customer did not provide account numbers
Electric service is provided by a joint utility	475	6	2 – Municipal electric – records not requested
Electric and/or natural gas bills were received from utility data requests	441	34	3 – Did not receive bills from utility data request
Account numbers are unique to address and bills are able to be aligned	434	7	4 – Cleaning
Adequate post-installation electric bills are available	408	26	5 – No post electric bills
No solar PV is installed on the building	330	78	6 – Solar PV present
GSHP site without GSHP baseline	312 314 - 310	18 16 - 20	7 – GSHP sites replacing existing GSHP systems
Post-installation electric bills meet sufficient actual read requirements	304 306 – 310	8 8 - 0	8 – Post electric bills >50% estimated
All tier-specific statistics tests are met	220 172 – 310	84 134 - 0	9 – Fails statistics tests
Total[1]	**220** **172 - 310**	**4,293** **4,341 – 4,203**	

1. The evaluation team calculated collected data and evaluated savings for 220 sites in the moderate scenario. Three pilot program sites were removed from the aggregate analysis due to the absence of program-reported savings. Two sites and five sites were removed from the strict and mild scenarios, respectively.

2.4.2 Analysis Filtering

Analyzing heat pump operation and savings via billing analysis is a complex task because the measure involves fuel switching, varying seasonal behaviors, load sharing with alternate HVAC systems, and in some cases, low use percentage compared to the whole building's load. Traditional weather-dependent billing analysis requirements, such as high R^2 results on analysis regressions, cannot always be applied to heat pump billing analyses.[1] In consultation with West Hill Energy and NYSERDA, the team developed three analysis filtering scenarios to present a range of evaluated results. Each scenario incorporates increasing levels of strictness in regard to data cleanliness, statistical significance, and weather dependency. This Phase 1 analysis is intended to be a preliminary result of the Heat Pump Evaluation project. The Phase 2 results will provide more definitive savings per site.

Table 2-4 presents the preliminary filtering steps that were imposed on all sites to determine how each would be evaluated. Adequate and clean post electric billing data is a minimum requirement of conducting each site's billing analysis. Any sites that did not meet all post-electric criteria presented in the table below were not included in the final evaluation sample, as identified in the "Treatment if Fail" column.

After the preliminary filtering was applied for post electric requirements, the evaluation team separated all billing data into individual cases, creating a single case for each fuel at each site for each billing period. The bills were split into two periods, a pre case and a post case, based on the installation date in the tracking data. For example, a single site could have up to 4 cases: pre electric, post electric, pre fuel, and post fuel. The evaluation team then reviewed each case individually to determine how it would be incorporated into the site's analysis. Table 2-4 presents the secondary filtering steps that were imposed on each case. Any individual dataset that does not pass the billing analysis requirements is then switched to use a modelled baseline analysis approach, which is discussed in Attachment A. In the moderate scenario, 44% of sites were analyzed using the billing analysis approach, at least partially, and 78% of sites were analyzed using the modelled approach partially or fully. These values sum to greater than 100% because sites with multiple fuels (e.g. electric and gas) could use both analysis methods, each applied to a different fuel (e.g. electric analyzed using billing analysis and gas analyzed using modelled analysis).

[1] R^2 indicates how much the variation in daily temperature explains the variation in daily energy use. A 1.0 R^2 means it explains all the variation; 0 means none.

Table 2-4. Electric Post-Installation Evaluation Filtering Criteria

Fuel Type	Period	Scenario	Days of Data	Bill Reads	R^2	t-test	Treatment if Fail
Electric	Pre	Strict	>180 days	<50% estimated	Any	>2	Model
		Moderate	>180 days	<50% estimated	Any	Any	Model
		Mild	>180 days	Any	Any	Any	Model
	Post	Strict	>270 days	<50% estimated	>0.6	>2	Drop
		Moderate	>270 days	<50% estimated	>0.2	Any	Drop
		Mild	>270 days	Any	Any	Any	Drop
Fossil Fuels[1,2]	Pre	Strict	>180 days	<50% estimated	Any	>2	Model
		Moderate	>180 days	<50% estimated	Any	>2	Model
		Mild	>180 days	Any	Any	Any	Model
	Post	Strict	>180 days	<50% estimated	>0.6	>2	Model
		Moderate	>180 days	<50% estimated	>0.6	>2	Model
		Mild	>180 days	Any	Any	Any	Model

1. Bill read requirements are not applicable to delivered fuels.
2. t-test requirements are not applicable to fossil fuel CDD regressions.

2.4.3 Aggregate Analysis

The final individual site analysis results were expanded to the sample frame using ratio estimation and a set of sample weights based on the sample design stratification to produce realization rates. Each weight is specific to an individual stratum and calculated as the number of units in the sample frame (N) for the stratum divided by the number of completed units in the sample (n) for the stratum. The interpretation of the weight is that each completed sample unit represents N/n units in the sample frame.

Notation: The following terms are used in calculating the realization rate for each fuel type:

T_j = Tracking estimate of gross savings for measure j

V_j = Verified estimate of gross savings for measure j

W_j = Weighting factor for measure j used to expand the sample to the population

S = Number of measures in the sample

The realization rates are calculated directly:

$$RR = \frac{\sum_{j=1}^{S} V_j w_j}{\sum_{j=1}^{S} T_j w_j}$$

Relative precision was calculated using the procedures described in Chapter 13 of the California Evaluation Framework[2].

[2] http://www.calmac.org/publications/California_Evaluation_Framework_June_2004.pdf

3 Results

The sections below present the results of the Phase 1 billing analysis, by heat pump type, fuel type, climate zone, building type, and several post-hoc segments of interest based on customer-reported data collected through the survey. These results are a preliminary look into the performance of NYSERDA's heat pump programs. Phase 2 of this study will provide more definitive results based on metering and verification (M&V) data and site-specific inspection findings. Additionally, the Phase 2 findings will provide deeper explanations into the main factors impacting the results, which can only be hypothesized via billing analysis.

Table 3-1 compares the total site energy savings (MMBtu) for both ASHP and GSHP, with the statewide realization rate. These results incorporate all fuels, including electric, natural gas, oil, and propane.

Relative precision is a normalized measure of uncertainty that is standard in the industry. For realization rates, it expresses uncertainty as a percentage of the verified gross savings (VGS) realization rate. Because the realization rates are so low in this study, they dramatically inflate the relative precision and appear to suggest a large amount of uncertainty. Table 3-1 includes the absolute precision as well. It shows the uncertainty in absolute terms as a percentage of 100% VGS realization rate. For example, in the moderate savings result, ERS estimates that the ASHP VGS realization rate is between 16% and 38% (27% ± 11%) with a 90% confidence.

Table 3-1. Statewide Billing Analysis Results by Heat Pump Type

Technology	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (Site MMBtu)[1]	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
ASHP	4,043	127 90 - 191	228,373	62,024 74,615 - 53,291	27% 33% - 23%	40% 43% - 30%	11% 14% - 7%
GSHP	470	90 80 - 114	42,858	21,787 20,622 - 18,965	51% 48% - 44%	16% 15% - 14%	8% 7% - 6%
Statewide	4,513	217 170 - 305	271,231	83,811 95,237 - 72,256	31% 35% - 27%	30% 33% - 22%	9% 12% - 6%

1. All MMBtu savings reported in this table and throughout the report are site MMBtu.

3.1 Air Source Heat Pump Results

Table 3-2 illustrates the air source heat pump results by fuel type. The program categorized all fossil fuel savings as oil rather than separating by fuel type, causing skewed fuel-specific results.

Table 3-2. ASHP Results by Fuel

Fuel	Units	n[1]	Gross (Program-Reported) Savings	Verified Gross Savings[3]	VGS Realization Rate[4]	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Electric	kWh	-	-19,632,240	-2,755,839 -1,680,631 - -1,861,358	14% 9% - 9%	61% 153% - 73%	9% 13% - 7%
Natural gas[2]	MMBtu	-	0	8,067 5,488 - 10,665	N/A -	N/A -	N/A -
Oil	MMBtu	-	295,359	38,508 39,002 - 32,291	13% 13% - 11%	47% 34% - 39%	6% 5% - 4%
Oil	Gallons	-	2,148,063	280,055 283,653 – 234,843	13% 13% - 11%	47% 34% - 39%	6% 5% - 4%
Propane[2]	MMBtu	-	0	23,643 26,223 - 12,207	N/A -	N/A -	N/A -
Propane[2]	Gallons	-	0	258,961 287,215 – 133,704	N/A -	N/A -	N/A -
All fossil fuels	MMBtu	-	295,359	71,426 80,348 - 59,641	24% 27% - 20%	37% 41% - 29%	9% 11% - 6%
Total energy	**MMBtu**	**127** 90 - 191	**228,373**	**62,024** 74,615 - 53,291	**27%** 33% - 23%	**40%** 43% - 30%	**11%** 14% - 7%

1. The evaluation team calculated savings for each fuel at all sites causing the n to be the same for all categories.
2. Realization rates cannot be calculated for these fuels because the program did not claim any savings in these categories. All fuel-based savings (i.e. non-electric savings) were categorized as oil for the ASHP program.
3. The column sums do not necessarily equal the total savings, for fossil fuel and overall, due to variation in statistical weighting when evaluation results are arranged by fuel category.
4. The total realization rate is greater than the individual fuel realization rates because the electric results are associated with negative impacts, which means there are greater savings than estimated by the program and therefore causes the total realization rate to increase.

The low VGS realization rates for both electricity and aggregate fossil fuels are indicative of lower than expected heat pump use.

Table 3-3 compares the results between centrally ducted and ductless mini-split ASHPs. Centrally ducted ASHPs represent a very small portion of the population, but the several sites included in the analysis population showed notably better results than ductless mini-split systems. This is due to the likelihood of ducted systems to serve the majority of conditioned floorspace because centrally ducted systems are inherently operated like traditional central conditioning systems that meet heating and cooling loads all year. Conversely, ductless mini-split systems can be installed to serve single zones, allowing a wide variety of applications, including individual room conditioning. This application variety enables a wide range of use behaviors; some of which result in less frequent use than a traditional central system. In Phase 2 of this study, the evaluation team will characterize each system by loading profile (partial vs. full load) for analytical comparison.

Table 3-3. ASHP Total Energy Results Per Site by Heat Pump Type

HP Type	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
Ductless Mini-split	**124** 88 - 188	**50** 52 - 48	**13** 17 - 11	**27%** 33% - 23%
Centrally Ducted	**3** 2 - 3	**36** 40 - 36	**23** 40 - 23	**64%** 100% - 64%

Table 3-4 presents the evaluated ASHP savings between the three NY climate zones. Climate zone 4, which primarily consists of New York City and Long Island, resulted in much lower savings than the other zones that encompass the majority of the state's landmass. The evaluation team hypothesizes that area type implications (urban vs. rural) and installation scenario (displacement vs. replacement) rather than climatic differences are the causal factors. This will be explored more in Phase 2. Installations in climate zone 4 also account for nearly 75% of the total population.

Table 3-4. ASHP Total Energy Results Per Site by Climate Zone

Climate Zone	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
4	**32** 21 - 54	**50** 44 - 47	**9** 9 - 8	**18%** 21% - 18%
5	**36** 24 - 50	**36** 38 - 36	**23** 31 - 18	**65%** 81% - 51%
6	**59** 45 - 87	**57** 64 - 56	**27** 33 - 19	**47%** 52% - 34%

All ASHP installations were in residential facilities; therefore, no building-type results are presented in this section.

3.2 Ground Source Heat Pump Results

Table 3-5 presents the results for GSHPs by fuel type. The program properly reported fuel-specific savings for GSHPs by breaking down fossil fuel savings into their respective fuel types. The natural gas realization rate is significantly higher than the other fuels due to the program incorrectly identifying some sites fuel type.

Table 3-5. GSHP Results by Fuel

Fuel	Units	n[1,2]	Gross (Program-Reported) Savings	Verified Gross Savings[3,4]	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Electric	kWh	-	-1,649,468	-344,174 -25,091 – -387,136	21% 2% - 23%	155% 2550% - 93%	32% 39% - 22%
Natural gas	MMBtu	-	8,053	15,310 14,585 - 13,429	190% 181% - 167%	77% 76% - 74%	146% 138% - 123%
Oil	MMBtu	-	33,252	12,742 10,850 - 11,058	38% 33% - 33%	27% 32% - 24%	10% 11% - 8%
Oil	Gallons	-	241,830	92,669 78,913 – 80,422	38% 33% - 33%	27% 32% - 24%	10% 11% - 8%
Propane	MMBtu	-	7,181	3,257 2,889 - 2,921	45% 40% - 41%	48% 48% - 43%	22% 19% - 18%
Propane	Gallons	-	78,655	35,676 31,639 – 31,999	45% 40% - 41%	48% 48% - 43%	22% 19% - 18%
All fossil fuels	MMBtu	-	48,485	22,800 20,634 – 19,969	47% 43% - 41%	47% 43% - 41%	19% 21% - 17%
Total energy	**MMBtu**	**108** 96 - 134	**42,858**	**21,787** 20,622 – 18,965	**51%** 48% - 44%	**16%** 15% - 14%	**8%** 7% - 6%

1. The evaluation team calculated savings for each fuel at all sites causing the n to be the same for all categories.
2. Per NYSERDA's request, all sites with a GSHP baseline system were removed from the analysis.
3. The variation in the range of results is due to the different analysis techniques applied to each site depending on the filtering criteria, as discussed in Section 2.4.2. The total energy saved is greatest in the moderate scenario because it includes a lower proportion of sites with billing analysis-based results than the strict scenario, and those sites overall tended to save less than modeling baseline sites, and removes the sites with little to no weather dependency (and typically less energy use and savings) that are kept in the mild scenario.
4. The column sums do not necessarily equal the total savings, for fossil fuel and overall, due to variation in statistical weighting when evaluation results are arranged by fuel category.

ERS investigated the differences in results by building type (i.e. residential vs. non-residential), but perhaps unsurprisingly, the three commercial sites had more program-reported savings and verified gross savings per site than the residential average. Regarding realization rates, the two smaller commercial sites' average was similar to that of the residential sites. The largest commercial site had a markedly higher realization rate, 130%. The commercial-specific realization rates can only be considered anecdotal evidence and are not statistically significant due to the small sample sizes. Each site's categorization is based on program tracking data. Through initial Phase 2 recruitment, the evaluation team has identified that some sites identified as commercial are actually large residences.

Table 3-6 presents GSHP results by climate zone. There are not enough installations in zone 4 to make any generalizations. The comparison between zones 5 and 6 indicates that there is some variation in GSHP performance between these strata, but the results are unclear whether it is due to weather. This comparison will be further investigated in Phase 2 of this study.

Table 3-6. GSHP Total Energy Results Per Site by Climate Zone

Climate Zone	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
4	**0** 0 - 0	**-** -	**-** -	**-** -
5	**64** 58 - 80	**102** 102 – 102	**46** 48 - 42	**45%** 47% - 41%
6	**26** 22 - 34	**94** 97 - 88	**61** 48 - 46	**65%** 50% - 53%

3.3 Segment-Specific Results

The following tables present results for both ASHPs and GSHPs combined, for various post-hoc segments of interest. These tables are based on customer-reported data collected through the survey. As discussed in Section 4, the evaluation team will further investigate many of the results presented in the following tables through Phase 2 of this impact evaluation.

Baseline plays an important role in calculating savings for heat pumps. Table 3-7 presents the savings results for the different customer-reported baseline scenarios. The lower new construction realization rates are also influenced by the evaluator's use of the new New York Technical Reference Manual (TRM) savings calculation formula based on the version submitted to the NY Public Service Commission in February 2020. The ASHP program did not account for baseline energy source, and the GSHP program used GSHP pro-forma tool. The evaluation team plans to further investigate baseline implications in Phase 2.

Table 3-7. Heat Pump Total Energy Savings Per Site by Space Type

Space Type	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
Existing space	**176** 135 - 248	**67** 70 - 63	**22** 26 - 19	**32%** 37% - 29%
Newly constructed	**21** 20 - 32	**102** 104 - 96	**20** 31 - 14	**20%** 30% - 15%

Table 3-8 presents the savings results based on customer-reported heat pump operating season. Deemed savings algorithms assume that heat pumps will be used year-round for both heating and cooling, which is an accurate assumption with over 90% of customers using their heat pumps year-round.

Table 3-8. Heat Pump Savings Per Site by Operating Season

Operating Season	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
Both	197 153 - 279	69 74 - 66	25 29 - 20	37% 39% - 30%
Cooling only	7 4 - 8	69 61 - 67	4 7 - 5	6% 12% - 8%
Heating only	13 13 - 18	91 91 - 79	43 50 - 20	48% 54% - 26%

Table 3-9 illustrates the savings results between the different customer-reported heating use case scenarios. After reporting that their heat pump is used for at least some heating, the survey asked respondents how much their existing heating system is still used. In cases where the customers continue to use their existing heating system frequently, the resulting savings are much lower. This not only indicates that customers must use heat pumps as the primary heating equipment to realize savings, but also that more than 25% of installations are not in high heating frequency scenarios.

Table 3-9. Heat Pump Total Energy Savings Per Site by Heating Displacement

Space Type	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
Existing heating used frequently	45 25 - 69	40 41 - 41	7 5 - 6	18% 11% - 15%
Existing heating used infrequently	38 33 - 59	63 66 - 55	25 32 - 21	40% 48% - 39%
No existing heating used	79 68 - 103	85 85 - 84	61 64 - 46	71% 75% - 55%

Table 3-10 presents savings results by customer-reported building vintage. Based on the spread of results across the different vintage categories, vintage does not have a major impact on heat pump savings. The team plans to further investigate envelope quality coupled with building vintage in Phase 2.

Table 3-10. Heat Pump Total Energy Savings Per Site by Building Vintage

Building Vintage	n	Gross (Program-Reported) Savings Per Site (MMBtu)	Verified Gross Savings Per Site (MMBtu)	VGS Realization Rate
Prior to 1940	**49** 38 - 71	**69** 72 - 61	**20** 24 - 16	**30%** 34% - 27%
1940-1978	**72** 58 - 100	**71** 73 - 64	**16** 18 - 14	**22%** 24% - 22%
1979-2006	**61** 44 - 84	**56** 61 - 59	**33** 61 - 24	**60%** 100% - 41%
2007-present	**23** 22 - 35	**101** 105 - 98	**28** 30 - 23	**27%** 29% - 24%

4 Preliminary Findings and Upcoming Research

Based on the results presented in Section 3, the evaluation team has developed preliminary findings regarding heat pump use cases and savings impacts.

- With ASHPs encompassing 90% of the population, their results have significant impacts on the VGS realization rates. A single deemed savings value per outdoor unit was applied to the entire population. This approach does not account for unit size, baseline, or climate. When the participant population consistently deviates from deemed assumptions, such as this program's high proportion of downstate installations and their lower annual heating loads, use of a deemed value not only contributes to evaluation variability but to bias. The evaluation team has not computed the contributions of each factor in Phase 1, but the claimed savings approach is inadequate.
- As evidenced by the heating displacement table (Table 3-10, above), savings are most realized when heat pumps are used as the primary heating equipment. Contrary to this understanding, heat pumps, especially ductless mini-splits, are versatile and cost-effective equipment that are installed for a wide variety of use cases, which do not always align with the highest energy-saving use case. Their versatility and use cases are factors that should be considered more when estimating savings.
- The evaluation team identified that ~20 GSHP installations in the population were replacing existing GSHP systems. This baseline is not currently addressed in the New York TRM. The evaluation team recommends that this baseline scenario be considered by the TRM Committee, as the team expects this to become more common as first generation GSHPs begin to reach their effective useful life. These sites were removed from the results presented in this memo, as requested by NYSERDA.

The second phase of this impact evaluation, which consists of advanced M&V at over 130 sites across the state, is currently being conducted. The evaluation team will use the results and findings from this billing analysis to enrich the Phase 2 analyses. Additionally, the team has identified several research questions throughout Phase 1 that will be investigated further in Phase 2, including:

- How much of the conditioned floorspace is served by the heat pump? Does it serve the whole house or just a portion?
- How much is the heat pump operated throughout the year? Is it used for both heating and cooling?
- How much is the existing conditioning equipment being used? How does this existing equipment interact with the heat pump? Do they serve separate spaces? Is the existing equipment only used to provide supplemental conditioning when the heat pump cannot meet the load?
- How do customers with solar and distributed energy resources operate their heat pumps differently than customers without? Customers with solar could not be included in the billing analysis because accurate electric use cannot be determined from bills alone. The evaluation team hypothesizes that customers with solar are more likely to use their heat pumps for a greater portion of their conditioning needs because they generate their own electricity, thus reducing operating costs.

ATTACHMENT A: DETAILED CLEANING AND ANALYSIS METHODOLOGY

This attachment provides a detailed description of the billing data acquisition and cleaning process, regression algorithms and logic, and application of engineering-based savings estimates that complemented the billing data analysis.

A1. Data Cleaning

In billing analysis, data cleaning and preparation includes the following processes:

1. Converting energy use data from utility companies and unregulated fuel providers across New York into a standardized form that can be associated with available weather data for analysis and compiling it with participant and survey data.
2. Excluding or repairing bad data.
3. Compiling weather data and associating it with the billing data.

A1.1. Acquire, Convert, and Compile Data

NYSERDA provided ERS with investor-owned utility (IOU) company electricity and natural gas data for nominally a year before and after equipment installation. NYSERDA drew some of the preliminary participant IOU billing data from the Electronic Data Interchange (EDI). IOUs provided billing data for 93% of requested accounts. The evaluators secured fuel data by going directly to the fuel supplier after securing releases from customers in the survey. ERS took the following steps to standardize the data:

1. Convert received raw column headers into standardized columns:
    - site_id = identifier for the site from NYSERDA tracking data
    - service_type = (gas, electric, oil, propane, or coal)
    - data_source = (utility_name or EDI)
    - billing_start_date = start of billing period
    - billing_end_date = end of billing period
    - read_type = (estimated or actual)
    - reading_value = numerical value
    - units = (therms, gallons, kWh, etc.)

    For utilities (i.e., fuel suppliers, Central Hudson, National Fuel) that only provided delivery dates, billing start dates were based on the prior bill's delivery date.
2. Anonymize utility account numbers and service_type (e.g., gas, electric, oil, propane) pairings by mapping an anonymized key (e.g. edi_key)

- edi_key = anonymized key to represent a unique utility account number and service type (i.e., gas, electric, oil, propane)

3. Consolidate billing data from utilities
   - Append data from each utility as new rows
4. Convert all fossil fuel reading values (i.e., gas, oil, propane, coal) into MMBtu

The team associated survey and application data (necessary for later analysis) with each participant before anonymizing it.

A1.2. Cleaning

Once compiled in a standard structure, the team developed logic to clean the data. Screening criteria were to delete individual period consumption records with:

- No start date
- An error response from EDI
- Coal
- Key entry errors detected with range checks, such as impossible end dates in the future, second instance of duplicates, improbably high use (values greater than 3 standard deviations from the mean were individually inspected)
- Drop data with overlapping periods and keep first instance
- For bills with duplicate data from EDI and the utility, keep data from the utility
- Estimated read status, after adding the estimated use to the next month's use. This was a routine step for IOUs with standard bimonthly reading and monthly billing.
- The period that included the installation date

Once individual reading data was cleaned, the team reviewed whole-home energy use patterns. Analysts excluded sites with insufficient data to perform a regression.

Finally, after the regression analysis described in Section A2 below, data cleaning removed sites due to:

- Inadequate post electric billing data, depending on the analysis scenario, as discussed in Section 2.4.2
- Sites with solar systems because accurate electric use cannot be deduced from billing data
- GSHP sites that were replacing existing GSHP systems, per NYSERDA's request

Total attrition rates by category are summarized in Section 2.4.1.

A1.3. Compile with Weather Data

ERS separately compiled hourly dry bulb temperatures from New York weather stations and processed each into daily average temperatures, heating degree days (HDD), and cooling degree days (CDD). Multiple sets of HDD and CDD were generated with different base temperatures, also known as balance point temperatures, as described in Section A2, below.

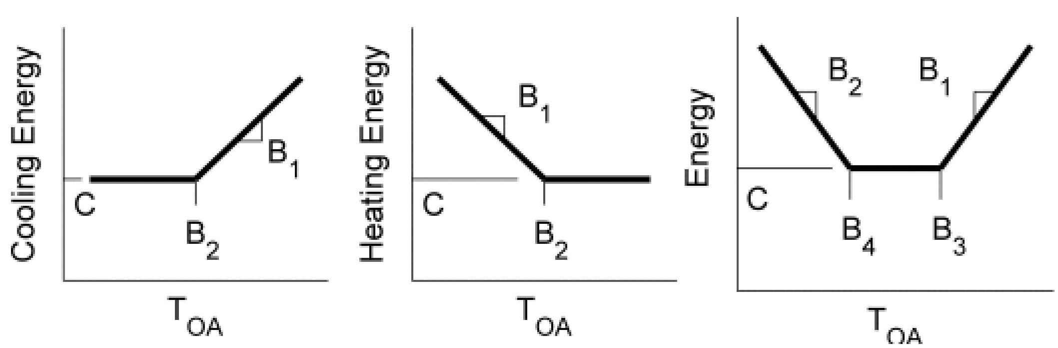
Each heat pump site then was associated with the nearest weather station. Consumption period data were combined and normalized with the daily weather data based on the meter read dates. The metered use and the degree days were divided by the number of days in the billing period to calculate the use per day, the CDD per day, and the HDD per day. For each day in each billing period, a data record was created with the use per day, HDD per day, and CDD per day.

A2. Billing Regressions and Grid Impacts

The team attempted a site-specific analysis on all billing data available. Iterations of regressions were performed with use per day as the dependent variable and either HDD per day, CDD per day, or both as the independent variables. The base temperatures of the HDD and CDD were also varied in the regression iterations to determine which base temperatures and which models (CDD only , HDD only, CDD and HDD, or baseload only [non-weather dependent]) provide the best fitting model for both pre and post. Figure A-1 illustrates these different "change point linear regression models." When referring to testing different base temperatures, this means finding the best curve fit by varying B_2 in the two curves at left or similarly, B_4 and B_3 in the curve at right.

Linear curves are used because both conduction and convection heat loss vary proportionally with inside-outside temperature difference. They also are simpler.

Figure A-1. Linear Change Point Regression Models[3]



[3] Mitchell T. Paulus, David E. Claridge, Charles Culp, "Algorithm for automating the selection of a temperature dependent change point model," Energy and Buildings, Volume 87, 2015, Pages 95-104, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2014.11.033.

Once the relationship between the site's energy use and outside temperature was established using actual weather data, these regressions were then used to calculate the normal long-term annual use by using recent 10-year average weather data.

Electric and fossil fuel billing savings were calculated based on the based on the filtering criteria discussed in Section 2.4.2. No R^2 filter was applied to the pre electric regressions for sites with existing fossil fuel equipment for inclusion as the pre electric is not expected to have the same weather dependence as the post.

The following equations calculate the normal modeled energy consumption for a given fuel and given case.

$$E_{case} = \sum_{i=1}^{365} C_{case} \times CDD_i + H_{case} \times HDD_i + B_{case}$$

$$EH_{case} = \sum_{i=1}^{365} H_{case} \times HDD_i$$

$$EC_{case} = \sum_{i=1}^{365} C_{case} \times CDD_i$$

where:

E_{case} = Annual energy of given case, pre or post and fuel type (kWh or MMBtu)

EH_{case} = Annual heating energy of given case, pre or post and fuel type (kWh or MMBtu)

EC_{case} = Annual cooling of given case, pre or post and fuel type (kWh or MMBtu)

HDD_i = Daily heating degree days of typical year weather for day *i*

CDD_i = Daily cooling degree days of typical year weather for day *i*

C_{case} = Cooling degree day constant for given case, pre or post and fuel type

H_{case} = Heating degree day constant for given case, pre or post and fuel type

B_{case} = Non weather dependent constant for given case, pre or post and fuel type

A3. Evaluated Impacts and Modeled Baselines

Billing analysis shows the difference in energy use between pre- and post-installation conditions. The measure's savings will differ from this comparison when the baseline is other than the pre-installation condition. There are three scenarios in which the evaluation team implemented a baseline other than pre-installation conditions, including:

1. New construction or renovation projects
2. Projects without cooling systems in the pre-installation scenario

3. Projects when the pre-installation regression was not possible due to lacking data or correlation

To model the baseline energy use in these scenarios, the evaluation team assumed a baseline system that minimally complies with energy efficiency standards or industry standard practice. The post-installation regressions were used to express post-installation and the pre-installation use was instead modeled using an engineering approach, leveraging the known post-installation use.

The calculations followed the most current New York TRM methods, assumptions, and resources. For sites with new construction baselines, this analysis follows the TRM recommended baseline practice:

- Minimally efficient ASHP for new construction ASHP
- Minimally efficient ASHP for new construction GSHPs where natural gas service is unavailable
- Gas-fired furnace for new construction GSHPs where natural gas service is available

For sites with existing conditions baselines, this analysis assumes baseline equipment and fuel types based on customer-reported values from the survey. This approach is taken to maintain consistency with the sites that use billing analysis approach. Specifically, the post-installation normalized electric heating and cooling energy was used to calculate the pre-installation heating and cooling energy by applying the ratio of the post- and pre-installation efficiencies to these heating and cooling energies.

For electric:

$$EC_{pre} = EC_{post} \times COPc_{post} \div COPc_{pre}$$

$$EH_{pre} = EH_{post} \times COPh_{post} \div COPh_{pre}$$

For fossil fuel:

$$FH_{pre} = EH_{post} \times COPh_{post} \times 3412 \div eff_{pre} \div 100{,}000$$

where:

FH_{pre} = Modeled baseline fuel heating energy in MMBtu

EH_{pre} = Modeled baseline electric heating energy in kWh

EC_{pre} = Modeled baseline electric cooling energy in kWh

EH_{post} = Normalized annual heating energy from post regression in kWh

EC_{post} = Normalized annual cooling energy from post regression in kWh

$COPh_{pre}$ = Baseline electric heating coefficient of performance

$COPh_{post}$ = Installed electric heating coefficient of performance

$COPc_{pre}$ = Baseline electric cooling coefficient of performance

$COPc_{post}$ = Installed electric cooling coefficient of performance

Seasonal efficiencies are computed from nameplate SEER and HSPF according to the TRM methodology. The calculations differ as a function of type of heat pump.

For air source:

$$COPh_{post} = a + b \times HPSF \div 3.412$$

$$COPc_{post} = c + d \times SEER \div 3.412$$

where:

a, b, c, d = coefficients from the TRM based on location and type of heat pump

$HPSF$ = Rated heating seasonal performance factor

$SEER$ = Rated seasonal energy efficiency ratio

For ground source:

$$EER_{season,ee} = ((F_{full} \times EER_{GLHP,full} \times 1.09 \times F_{pump,full}) + (F_{part} \times EER_{GLHP,part} \times F_{pump,part})) \times F_{dist,c}$$

$$COPc_{post} = \text{EER}_{\text{season, ee}}$$

$$COPc_{post} = \left((0.25 \times EER_{full} \times 1.09 \times 0.93) + (0.75 \times EER_{part} \times 0.89) \right) \times 0.95 \div 3.412$$

$$COP_{season,ee} = ((F_{full} \times COP_{GLHP,full} \times 1.08 \times F_{pump,full}) + (F_{part} \times COP_{GLHP,part} \times F_{pump,part})) \times F_{dist,h}$$

$$COPh_{post} = \text{COP}_{\text{season, ee}}$$

$$COPh_{post} = \left((0.25 \times COP_{full} \times 1.08 \times 0.93) + (0.75 \times COP_{full} \times 0.89) \right) \times 0.96$$

where:

$COP_{GLHP,full}$ = Rated COP of the unit at GLHP full load heating conditions

$COP_{GLHP,part}$ = Rated COP of the unit at GLHP part load heating conditions

$EER_{GLHP,full}$ = Rated EER of the unit at GLHP full load cooling conditions

$EER_{GLHP,part}$ = Rated EER of the unit at GLHP part load cooling conditions

$F_{dist,c}$ = Factor to adjust the cooling efficiency to account for additional fan power

$F_{dist,h}$ = Factor to adjust the heating efficiency to account for additional fan power

F_{full} = Seasonal weighting factor for full load efficiency

F_{part} = Seasonal weighting factor for part load efficiency

$F_{pump, part}$ = Factor to adjust part load efficiency to account for additional pumping power

$F_{pump,full}$ = Factor to adjust full load efficiency to account for additional pumping power

1.09 = Correction for change in cooling performance

1.08 = Correction for change in heating performance

The efficiencies used for the baseline presented in Tables A-1 and A-2 were based on the most recent TRM for residential air source and ground source heat pumps. The SEER was used to calculate the baseline COPc.

Table A-1. Baseline Cooling Performance

Baseline Cooling Equipment	SEER
Central AC	13
Window AC	14
Heat pump	14
New construction	13

Table A-2. Baseline Heating Performance

Baseline Heating Equipment	Performance Type	Performance Value
Oil – all	Efficiency	0.83
Gas furnace	Efficiency	0.8
Gas water	Efficiency	0.82
Gas steam	Efficiency	0.82
Heat pump	COP	2.40
Electric resistance	COP	1.0

APPENDIX F. PHASE 2 SAMPLE DESIGN MEMO

On February 18, 2020, DNV submitted to NYSERDA a memorandum detailing the sample design for Phase 2 measurement and verification. A copy of the memo is included in this appendix.

Memo to:
Tracey DeSimone, NYSERDA

From: DNV GL Energy Insights
Date: 2/18/2020

Copied to:
Kelly O'Connell, ERS
Jon Maxwell, ERS

Sample Design Approach for NYSERDA Heat Pump Impact Evaluation

1 OBJECTIVE

This memo provides a sample plan for the NYSERDA Heat Pump Impact Evaluation. The evaluation originally planned for a census of the Phase 1 survey; changes to the project team and data collection approach (incorporating APPRISE with a CATI approach) resulted in revisiting the assumed response rate for phone data collection. This memo documents the updated sampling approach, along with the Phase II sampling approach.

2 STARTING ASSUMPTIONS

The evaluation plan, guided by the mini-bid RFP, specifies 90/10 precision targets for both Phase 1 (survey and billing analysis) and Phase 2 (on-site tracking), for ASHP and GSHP separately. Phase 2 participants are drawn from Phase 1 respondents who respond to the survey request, complete the survey, have clean billing data, and agree to on-site tracking. As a result, the survey has three required sample sizes for each ASHP and GSHP; total survey completions, those agreeing to share billing data (P1 Billing), and those willing to participate in on-site tracking (P2 On-Site), shown in Table 1.

It was initially assumed that due to various factors, there would be only 18 useable Ground Source Heat Pump respondents willing and eligible for on-site metering in Phase 2. This would result in a precision of 15% at 90% confidence (90/10). For a fuller description of starting assumptions that identified these estimated necessary sample sizes, please refer to the full Work Plan.

Table 1: Initial Sample Targets for 90/10 Precision

<table>
<tr><th>Phase</th><th>Air Source Heat Pumps</th><th>Ground Source Heat Pumps</th></tr>
<tr><td>Survey Completions</td><td rowspan="2">67</td><td rowspan="2">60</td></tr>
<tr><td>P1 Billing</td></tr>
<tr><td>P2 On-Site</td><td>97</td><td>18 (40)</td></tr>
</table>

3 REVISED ASSUMPTIONS

Survey execution was done first through a web survey and then through phone. A web survey was sent to *all* participants with a matched email address. The initial results of that web survey created a need for updated targets for those agreeing to on-site metering contact, shown in Table 2 and explained below.

P2 On-Site: Simple

The survey achieved response rates exceeding initial assumptions; upwards of 75% of respondents agreed to share their billing information and/or to be contacted to have metering equipment installed on-site. As a result, the evaluation team updated survey response targets by assuming necessary precision of 90/10 for both ASHP *and* GSHP. It was originally estimated that only about 18 GSHP sites would agree to on-site metering; results of the online instrument showed this assumption to be incorrect and the 90/10 precision target of 40 was restored.

This simple precision goal is the full number of on-sites estimated to be required to meet the precision target.

P2 On-Site: Sum of Subgroups

NYSERDA identified that while 90/10 precision for ASHP and GSHP as the primary requirement, there was also a desire to ensure that survey respondents represented additional sub-groups. These included ASHP equipment sub-type, the climate zone, and the building type (residential, large commercial, small commercial, and other).

90/10 precision was not required for these sub-groups, dividing the sample proportionally resulted in an overall increase in the target size because fractional prorations were rounded *up*, as it is not possible to target a fraction of a complete. The evaluator prorated targets for these groups within the targets defined by 90/10 precision for ASHP and GSHP and rounded up any fractional targets, resulting in increased targets at those required levels.

P2 On-Site: Attrition Pool

Because attrition is unknown (respondent data entry error, missing billing data, later on-site refusal), the evaluator and NYSERDA project staff agreed to adapt the targets. The evaluator worked to ensure that unknown attrition would be safely accounted for by assuming 90/10 precision for both and doubling the estimated required number of completions.

This target was created to establish a pool to attempt to achieve the 137 total on-sites needed for 90/10 precision. This pool is not implying that 312 on-sites will be conducted, but are a total available pool to account for attrition and help ensure that the precision targets of 90/10 are achieved.

Table 2: Phase 1 Survey Target Responses

<table>
<tr><th>Phase</th><th>Air Source Heat Pumps</th><th>Ground Source Heat Pumps</th></tr>
<tr><td>Survey Completions</td><td rowspan="2">67</td><td rowspan="2">60</td></tr>
<tr><td>P1 Billing</td></tr>
<tr><td>▪ P2 On-site: Simple</td><td>97</td><td>40</td></tr>
<tr><td>- P2 On-site: Sum of Subgroups</td><td>106</td><td>50</td></tr>
<tr><td>- P2 On-site: Attrition Pool</td><td>212</td><td>100</td></tr>
</table>

At the close of data collection efforts, there were 775 total completions recorded after initial data cleaning removed obvious incomplete surveys and duplicate surveys. Table 3 shows breakouts of the 775 total completions (545 ASHP and 230 GSHP).

Table 3: Phase 1 - Web & Phone

Stratum	Population	P2 Target	Total complete	Agreed to data	Agreed to on-site
ASHP	**4045**	**212**	**545**	**295**	**385**
ASHP Combo	2	2	2	2	2
5	1	1	1	1	1
Residential	1	1	1	1	1
6	1	1	1	1	1
Residential	1	1	1	1	1
ASHP Ducted	10	3	7	4	6
4	2	1	2	2	2
Residential	2	1	2	2	2
5	6	1	3	0	2
Residential	6	1	3	0	2
6	2	1	2	2	2
Residential	2	1	2	2	2
ASHP Ductless	4033	202	536	289	377
4	2967	146	276	102	153
Residential	2967	146	276	102	153
5	412	22	89	63	76
Residential	412	22	89	63	76
6	654	34	171	124	148
Residential	654	34	171	124	148
GSHP	**470**	**100**	**230**	**193**	**205**
4	23	10	14	8	13
Large Commercial	1	1	0	0	0
Other	1	1	1	1	1
Residential	21	6	13	7	12
5	307	60	147	127	126
Large Commercial	4	1	2	1	2
Residential	299	56	141	122	121
Small Commercial	4	2	4	4	3
6	140	30	69	58	66
Large Commercial	1	1	1	0	1
Other	1	1	1	1	1
Residential	131	24	65	57	62
Small Commercial	7	2	2	0	2
Grand Total	**4515**	**312**	**775**	**488**	**590**

Multiple Applications

We identified thirty-five instances where survey respondents had more than one application number, but only one survey completion; these instances are categorized as “multiple applications”. Thirty-three multiples agreed to be contacted for on-site metering. As there was not a survey completed for these additional applications, there is not yet verification of records or indication that these extra sites may be metered. As a result, they will not be included explicitly in a sample plan for Phase 2. For these sites with multiple applications, if selected for on-site metering, meters will be installed on equipment for non-surveyed applications only if additional meters are not required (each meter can measure up to 3 circuits). If additional meters are required for the incremental units, they will not be metered.

Multiple Units

We also identified that many applications have multiple units. There are physical and data limits to how many pieces of equipment will be metered. As a result, it may not be possible to meter every unit in each application site scheduled for metering. A decision tree will be created as part of the on-site instructions for engineers to determine which units to meter; basic criteria to include grouping units first by control type and then by unit size.

4 PHASE 2 PLAN

The universe available for sampling for on-site metering is from the available completions, utilizing the 590 respondents that agreed to be contacted for metering.[1] This 590 is the number of respondents based on application, not on-site, address, total number of units or other measure. DNV GL has prepared a sample plan that uses the top-level, technology targets for overall targets (ASHP & GSHP, estimated 90/10), and applies the population proportion represented by those targets to each of the detailed substrata. The following rules were applied to collapse strata:

- AHSP Combo was removed, as can be noted in the difference between the ASHP population totals between Table 3 and Table 4
- Geographies with single customer types collapse to geography level
    - As all ASHP are residential, these were all collapsed to the geography level.
- Customer types with one available respondent collapse to geography
    - Distinction between Residential and Non-Residential was preserved. While there is only one available GSHP Non-Residential respondent in Zone 4, there are 8 others in Zones 4 and 5, thus the strata were preserved.

Final samples at the technology are calculated by summing the targets at the individual level. Also calculated is the implied relative precision using the previous assumptions about variability. A relative precision value was not provided for any substrata where the assumed population is less than 10, in such a case the proportional sample would inherently be small, and any meaningful inference would be beyond the intent of this study.

[1] NYSERDA approved drawing the sample from all positive respondents rather than from the subset of respondents with clean billing data to expedite Phase 2.

Table 4: Phase 2 Sampling Plan for On-Site Metering from Phase 1 Survey

Technology	Equipment Sub-Type	Geography	Customer Type	Available Respondents (On-Site Pool)	On-Site Target	Detailed Target	Implied Approximate Relative Precision
ASHP	**Total**			**383**	**97**	**97**	10.02%
	ASHP Ducted	*Total*		*6*		*4*	*49.35%*
	ASHP Ductless	*Total*		*377*		*93*	*10.23%*
		4	Total	153		64	12.34%
		5	Total	76		12	28.49%
		6	Total	148		17	23.94%
GSHP	**Total**			**205**	**40**	**40**	**10.40%**
		4	*Total*	*13*		*3*	---
			Non-Residential	1		1	---
			Residential	12		1	---
		5	*Total*	*126*		*22*	*14.03%*
			Non-Residential	5		2	---
			Residential	121		20	14.71%
		6	*Total*	*66*		*15*	*16.99%*
			Non-Residential	3		3	---
			Residential	62		12	18.99%

*ASHP strata are collapsed as all are identified as "Residential" within the population data.

APPENDIX G. PHASE 2 INTERIM HEATING MEMO

On September 20, 2021, DNV submitted to NYSERDA a memorandum summarizing the interim results from Phase 2 M&V analysis during the heating season of 2020-2021. A copy of the memo is included in this appendix.

Memo to: Tracey DeSimone, Elizabeth Boulton, Jennifer Meissner, and Victoria Engel-Fowles, NYSERDA

From: Patrick Hewlett, Nathan Throop, and Praga Meyyappan, DNV

Copied to: Jon Maxwell, DNV

Date: August 20, 2021 (original)
September 20, 2021 (revised)

NYSERDA Heat Pump Impact Evaluation – Interim Heating Results

This memorandum presents the methodology and heating season results of the NYSERDA Heat Pump Impact Evaluation Phase 2 Measurement and Verification.

1 EXECUTIVE SUMMARY

DNV is contracted by NYSERDA to evaluate the performance and energy impacts of ductless mini-split and centrally ducted air-source heat pumps (ASHPs) and ground-source heat pumps (GSHPs) incentivized by three NYSERDA initiatives through 2018: Underutilized Products (ASHP), Heat Pumps and Solar Thermal (GSHP), and the Heat Pump Pilot Projects Demonstration. This memo focuses on heating impacts determined during Phase 2 of the evaluation, which involves year-long, continuous measurement and verification (M&V) among a sample of participating customers. Phase 1 of the evaluation, which involved analysis of pre- and post-installation consumption data, including both utility billing and delivered fuels data, showed MMBtu[1] realization rates[2] of 27% and 51% for ASHPs and GSHPs, respectively.

Phase 2 demonstrated similar results to Phase 1 while providing more granular information for improving savings claims moving forward. Overall, NYSERDA-sponsored heat pump installations realized 31% of program-reported MMBtu savings during the heating season, with ASHPs and GSHPs realizing 26% and 53% of program-reported MMBtu savings, respectively. While site-specific performance data is still pending for the sample of GSHP projects, evaluators have identified key contributors to lower realized savings for ASHPs and GSHPs.

Program-reported savings for all ASHP projects—both ducted and ductless—were based on a NEEP estimate of whole-home heating oil consumption, derated to account for a portion of partial-displacement installations.[3] However, over 99% of ASHP installations through 2018 were ductless mini-split heat pumps (DMSHPs), which typically serve limited space(s) of the residence or business. Evaluators determined an average heating output of 13,302 kBtu per year for each installed ASHP system, as compared with the program planning assumption of 30,440 kBtu per year. Reduced heating output was the primary contributor to the 26% MMBtu RR for ASHPs. Evaluators observed sharp contrast in RRs between customers that removed the pre-existing heating system (55% MMBtu RR) and customers that did not (23-25% RR).

GSHPs similarly operated less frequently than predicted by the program. Through comparison of annualized heating output and nameplate capacity, evaluators determined 1,445 equivalent full-load heating hours (EFLHH) as compared with the program's assumed range of 2,230 to 2,604 EFLHH by region. Evaluated GSHP savings were further reduced due to poorer-than-assumed performance based on two sites that underwent more rigorous M&V. Evaluators have not yet retrieved

[1] All MMBtu savings in this report reflect *site* MMBtu— i.e., no electric production, transmission, or distribution efficiencies are incorporated.

[2] A realization rate is the ratio of evaluated savings to program-reported savings.

[3] For the whole-home heating consumption value, the Northeast Energy Efficiency Partnerships (NEEP) study referenced the Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS) database, filtered for residences in the Northeast: "Table CE4.7 Household Site End-Use Consumption by Fuel in the Northeast Region, Averages, 2009," http://www.eia.gov/consumption/residential/data/2009/c&e/enduse/xls/CE4.7%20Average%20Site%20EndUse%20Consumption%20by%20Fuel%20in%20Btu_Northeast.xlsx.

the supply and return groundwater loop temperature loggers at the 40 sampled GSHP sites. Groundwater temperatures greatly influence GSHP performance; therefore, the GSHP heating impacts presented in this memo are interim values that will be revised in the evaluation final report anticipated in December 2021.

The heat pump landscape in New York has changed greatly since the 2018 evaluation timeframe. Through joint coordination with the New York Department of Public Service (DPS), New York utilities now administer Clean Heat programs that sponsor expanded offerings such as heat pump water heaters (HPWHs) and custom installations. Program savings claims have similarly evolved, most importantly distinguishing between whole-home and partial-home installations. This memo's interim heating results show the importance of this distinction, as the ASHP RR in particular would have increased dramatically with right-sized savings claims for DMSHPs. In parallel with the conclusion of this evaluation study, DNV is collaborating with the New York DPS to launch a Technical Study of New York State Heat Pump Performance, which will improve heat pump savings algorithms and assumptions through techniques that build on this evaluation's. DNV and the DPS plan to leverage the M&V research conducted in this study to bolster the breadth and depth of real-world results in the next study and beyond to quantify the most representative performance factors for heat pump savings estimation in New York.

2 PROGRAM BACKGROUND AND EVALUATION OBJECTIVES

This evaluation study assesses the performance and energy impacts of ductless mini-split and centrally ducted ASHPs and GSHPs incentivized by three NYSERDA initiatives through 2018: Underutilized Products (ASHP), Heat Pumps and Solar Thermal (GSHP), and the Heat Pump Pilot Projects Demonstration. The impact evaluation is divided into two phases corresponding to the objectives identified in Table 2-1. Phase 1 methods and results were addressed in a memo delivered to NYSERDA on November 18, 2020.

Table 2-1. NYSERDA Heat Pump Impact Evaluation Objectives by Phase

Objective	Phase 1	Phase 2
Evaluate annual gross energy impacts of ASHPs and GSHPs[4]	X	X
Establish appropriate baseline conditions	X	X
Characterize seasonal usage of ASHPs and GSHPs	X	X
Assess displacement versus replacement	X	X
Characterize and document HP control systems and usage patterns	X	X
Characterize equipment issues that impact performance	X	X
Collect information on refrigerant		X
Confirm and refine billing analysis through seasonal on-site metering		X

This memo presents Phase 2 methods and results that achieve the following objectives for heating season impacts only:

- Evaluate annual gross heating season energy impacts of ASHPs and GSHPs. Through the M&V and analysis methodologies described in Section 2, Phase 2 quantifies the energy impacts among electric, natural gas, fuel oil, and propane fuel sources. The results will be updated with cooling season impacts as estimated through continuous on-site monitoring through the cooling season.
- Establish appropriate baseline conditions. Surveys and on-site discussions with participants provided context on pre- and post-installation conditions at the customer facility or residence in order to confirm pre-project conditions as representative of baseline or to inform a hypothetical or code-compliant baseline.

[4] Electric demand impacts are not a focus of this study.

- Characterize seasonal usage of ASHPs and GSHPs. Equipment-level M&V data allows the evaluators to further characterize heat pump operation as initially reported at the utility account level in Phase 1.
- Assess displacement versus replacement, control systems, and usage patterns. Participant surveys provided additional context on whether the heat pumps supplemented or replaced existing HVAC systems and how each system operates.
- Characterize equipment issues that impact performance. Using metered data and participant survey responses, evaluators identified reasons for deviation between evaluated and reported impacts.
- Confirm and refine billing analysis through seasonal on-site metering. Phase 2 heating results are compared and contrasted with Phase 1 billing analysis results to identify the benefits and risks with at-the-meter impact analysis of heat pump installations.

The evaluation final report, anticipated in December 2021, will address the remaining objective related to refrigerant.

3 METHODOLOGY

This section describes the methods used to collect and analyze the Phase 2 data to quantify heating season impacts.

3.1 Customer Survey

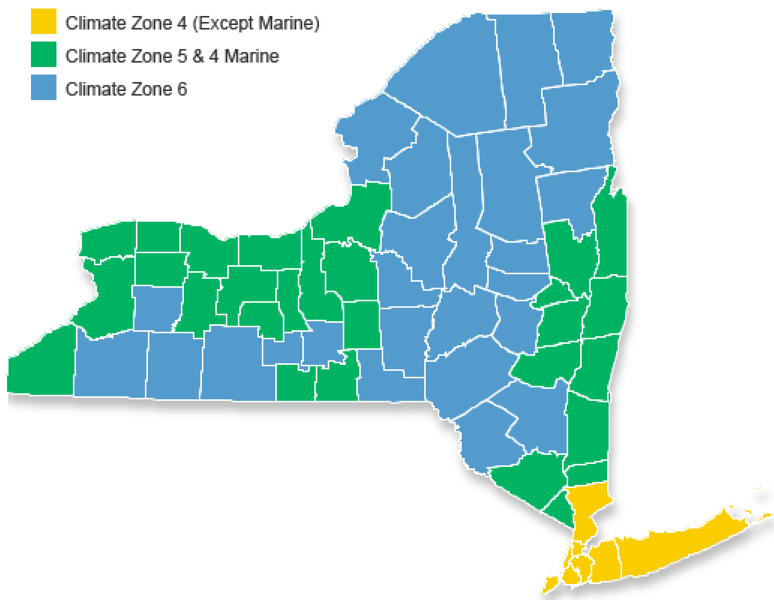
The evaluation team initiated data collection with a Qualtrics-based mixed-mode survey among prior program participants to collect data on installed heat pump characteristics and use patterns, customer demographics, and utility account information. The DNV team attempted a census by inviting all 4,515 program participants either via email or letter to respond to the survey. APPRISE, a computer-assisted telephone interviewing (CATI) firm, provided CATI services to follow up with customers in segments with low response rates. The survey responses provided a more in-depth understanding of how the heat pumps are being used and how much they are displacing heating and cooling loads served by existing HVAC equipment.

Additionally, the survey gathered valuable information to assist both phases of the evaluation. For Phase 1, the survey collected customer authorizations that allowed DNV to request utility and delivered fuel account information. It also collected data on any occupancy changes or other major non-routine events that occurred during the billing analysis period. The survey also introduced Phase 2 of the study to respondents and invited customers to participate in future on-site monitoring. To increase response rates and decrease possibility of nonresponse bias, DNV offered incentives for both survey completion and authorization of billing data access. Respondents that only completed the survey questions received a $15 incentive and respondents that also provided billing data authorization received an additional $35 incentive. The survey received 775 complete responses, exceeding initial expectations, and 448 respondents agreed to provide utility data authorization. A separate survey results memo, delivered to NYSERDA on November 24, 2020, describes the survey methods and responses in more detail.

3.2 Sample Design

While a census of the population was attempted with the customer survey, nonresponse was expected, and the team identified specific completion targets for each technology and climate zone stratum based on both phases' objectives, as shown in Table 2-1. Figure 3-1 illustrates the climate zone (CZ) designations in New York.

Figure 3-1. New York State Climate Zones by County



Of the 775 customers that completed the survey, 588 agreed to be contacted to have metering equipment installed on-site and/or to share their billing information. Table 3-1 provides the Phase 2 M&V sample design among the 588 available respondents, stratified by equipment type, climate zone, and customer type.

Table 3-1. Phase 2 M&V Sample Design Based on Phase 1 Survey Respondents

Tech.	Equip. Sub-Type	CZ	Customer Type*	Pop.	Available Respondents (On-Site Pool)	On-Site Target	Detailed Target	Implied Approximate Relative Precision	Final Completed Count
ASHP	**ASHP Total**			**4,043**	**383**	**97**	**97**	**10%**	**97**
	ASHP Ducted		Total	10	6		4	49%	3
	ASHP Ductless		Total	4,033	377		93	10%	94
		4	Total	2,967	153		64	12%	29
		5	Total	412	76		12	28%	25
		6	Total	654	148		17	24%	40
GSHP	**GSHP Total**			**470**	**205**	**40**	**40**	**10%**	**40**
		4	Total	23	13		3	---	3
			Non-Residential	2	1		1	---	1
			Residential	21	12		1	---	2

Tech.	Equip. Sub-Type	CZ	Customer Type*	Pop.	Available Respondents (On-Site Pool)	On-Site Target	Detailed Target	Implied Approximate Relative Precision	Final Completed Count
		5	Total	307	126		22	14%	22
			Non-Residential	8	5		2	---	2
			Residential	299	121		20	15%	20
		6	Total	140	66		15	17%	15
			Non-Residential	9	3		3	---	3
			Residential	131	62		12	19%	12

* ASHP strata by customer type are collapsed as all are identified as “Residential” within the respondent pool and on-site sample.

Despite the initial interest of the 588 surveyed participants, many hesitated to participate in the Phase 2 metering portion of the study due to concerns about in-home visits during the COVID-19 pandemic. Downstate respondents were particularly reluctant. Nonetheless, evaluators reached the total sample target of 137, albeit with segment-specific variation between targeted and completed counts for Ductless ASHP.

3.3 Billing Analysis

This Phase 2 memo compares the new equipment-specific metering results with the previously presented premise-level utility consumption data-based results. The methodology used for the premise-level analysis is described in the memorandum *NYSERDA Heat Pump Evaluation Phase 1 Billing Analysis Results*, November 18, 2020.

3.4 On-Site M&V

DNV field engineers deployed equipment metering devices at each of the 137 sampled facilities. On-site data collection procedures varied depending on the installed HVAC equipment types and the selected level of metering rigor. After at least 10 months of performance monitoring and data transmission[5], the evaluation team will collect all deployed metering devices, anticipated in Fall 2021. Participating customers will be provided a supplemental gift card for the return visit and their yearlong participation in the study. Field evaluators will use the final visits to clarify any outstanding or uncertain information as identified in the analysis phase.

3.4.1 Customer Interview and Walkthrough

The field engineer conducted an interview with knowledgeable facility contact(s) at the beginning of each site visit. Interview responses often prompted the field engineer to collect further information as applicable. For example, if the facility still consumed delivered fuels such as oil or propane, the field engineers requested copies of recent fuel delivery receipts as available.

[5] The first site visits occurred in February 2020. Logger deployments were shortly halted thereafter due to the COVID-19 pandemic. DNV and NYSERDA agreed to reinitiate site visits in July 2020, completing the final logger deployments by November 2020. The metering period is therefore expected to range from 10 months (for the last deployments) to 19 months (for the earliest deployments). The 10-month sites cover the full range of outside air temperatures in both winter and summer seasons.

The customer then led the field engineer in a walkthrough of the residence or commercial facility. Field engineers inspected all components of the installed heat pump(s), associated thermostats and controls, and any auxiliary heating/cooling equipment still in use. If present, any preexisting and/or ancillary HVAC systems were inspected and documented. Field engineers identified and documented the areas and characteristics served by the heat pumps and other HVAC systems, photographing all relevant HVAC equipment, thermostats, nameplates, and other relevant equipment or building characteristics.

Approximately 60% of sampled applications included more than one distinct heat pump unit rebated by the program. With limited metering equipment available for deployment, the evaluation team implemented a protocol for selection of metering equipment to be metered based on application, controls classification, and size.

3.4.2 Core M&V

Field evaluators executed the below M&V procedures at 125 of the 137 sites in the evaluation sample. The core procedures represent industry-standard approaches with the addition of advanced communicating devices for heat pump evaluation as concluded in DNV's preceding literature review, delivered to NYSERDA in February 2020. The advanced communicating metering devices operated using a data platform provided by DNV's software-as-a-service (SaaS) contractor.

The core protocol targeted the following relevant points for long-term measurement and/or spot measurement. The below points were metered for a selection of installed heat pumps at each of the 137 sampled projects. Contracted, licensed electricians performed all electrical metering equipment deployments under the guidance of a DNV field engineer.

- Long-term circuit amperage:
  - Compressor circuit
  - The compressor circuit often included any outdoor fans
  - For DMSHPs, the outdoor unit circuits also fed indoor units
  - Distribution fan circuit
  - GSHPs – groundwater pump circuit
  - Amperage characterizing the operation of any preexisting and/or auxiliary HVAC equipment (e.g., the combustion air fan for a preexisting boiler still in operation)
- Spot measurements of amperage, voltage, real power, and power factor for all metered circuits under a range of part and full-load operating conditions at steady-state
- Long-term temperature metering
  - Supply air stream
  - GSHP supply and return water pipe surface temperature
- Spot combustion efficiency measurement of preexisting/auxiliary heating system (if applicable)
- Spot measurement of outdoor air conditions during electrical spot measurements

The metering equipment deployed using remote monitoring technology is designed to continuously transmit metered data remotely over a cellular network. If the cellular signal was insufficient, field engineers utilized the facility's ethernet with the permission of the site contact. The SaaS gateway device requires continuous AC power to gather and transmit M&V data. To prevent any tampering with the gateway or any other deployed metering equipment, the field engineers instructed the customers to not interfere with the metering equipment or power cables. In some isolated instances, DNV was able to resolve the power or transmission issues remotely with the participants. Otherwise, DNV staff and/or licensed electricians redeployed or replaced the batteries in remote meters ensure maximum data coverage throughout the 10-19 months of metering.

To finalize the core M&V deployment, the field engineer confirmed that the deployed metering equipment was properly functioning and transmitting data. DNV staff confirmed data transmission to the SaaS communication platform after each meter deployment and continuously thereafter.

The long-term temperature metering is local and not cloud-based. Analysts will collect the logged temperature data at the end of the cooling season. Phase 2 GSHP heating results do not reflect temperature logging results and are preliminary in part because of this.

3.4.3 Intensive M&V

Intensive M&V sites supplement the core approach with laboratory-grade measurement rigor. The team implemented this intensive metering approach for 12 of the 137 sites in the Phase 2 sample with the intent of collecting real-world performance data to inform the 125 core sites and reveal potential areas of focus in future studies. The intensive metering sites were selected to represent at least one of each major type of heat pump (e.g., ducted ASHP, ductless mini-split heat pump (DMSHP), GSHP) in each of the three NY climate zones.

The intensive protocol includes relevant spot measurements of the core protocol and further targets the following relevant points for long-term measurement and/or spot measurement:

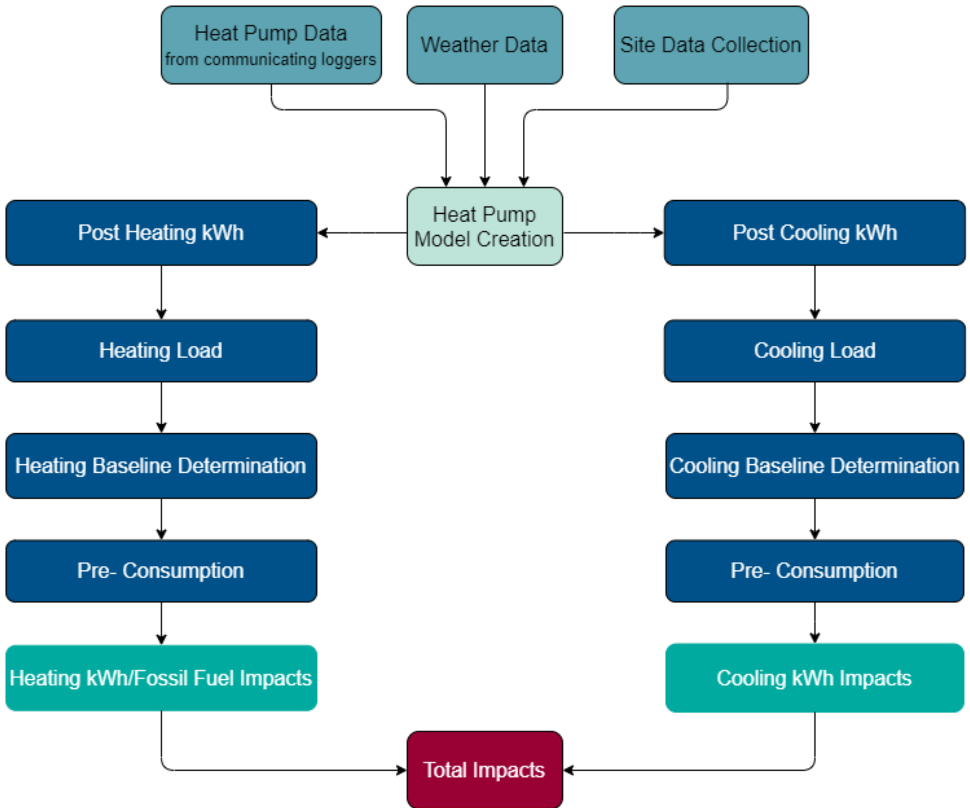
- Spot measurements of airflow
  - Anemometer with spot amperage readings of fan circuit for correlations made at various speeds
  - For ductless systems, a balometer/flow hood with spot amperage readings
- Long-term true RMS power metering: voltage, amperage, real power, power factor
  - Intended to collect potential power factor fluctuations
  - Separate metering for fans or pumps (as applicable depending on heat pump type)
- Long-term temperatures and relative humidity values (allowing for COP calculation)
  - Supply and return air streams (before and after coils)

Contracted, licensed electricians performed all electrical metering equipment deployments under the guidance of a DNV senior engineer.

3.5 Site-Specific Analysis

On-site M&V is intended to provide sufficient data to develop pre- and post-installation heating and cooling loads and subsequent associated impacts by fuel type. The sections below briefly summarize the evaluation team's approach to quantifying gross, first-year impacts from NYSERDA-rebated heat pump installations. Figure 3-2 illustrates the overall analysis approach. Appendix A: Detailed Phase 2 Analysis Methods includes two diagrams that provide additional detail on analysis methods.

Figure 3-2. Heat Pump Analysis Workflow



3.5.1 Installed Condition

DNV's metering approach captures the operation and performance of the installed heat pump system components as well as relevant auxiliary heating/cooling systems sharing the facility's loads. The evaluation analysts processed metered interval data to characterize the heat pump's heating/cooling loads and operational patterns. Heat pump operation data was correlated with outside air temperatures over the metering period to determine the weather effects on heat pump operation. These correlations were extrapolated over a full year using typical weather data[6] for the most proximate weather station in New York. For heat pumps not selected for M&V but installed at sites receiving M&V, evaluators leveraged M&V results from HVAC equipment with similar operational characteristics (e.g., controls, space type served).

For heat pumps sharing the building's total heating/cooling loads with other HVAC equipment, the evaluators used the Phase 2 metered data to quantify the hour-by-hour load sharing as a function of key independent variable(s) such as outside air temperature or time of day.

3.5.2 Baseline Condition

The evaluation analysts considered different data sources to establish the most appropriate, site-specific heating baselines, as follows.

[6] Acknowledging the changes in climate since the latest typical meteorological year (TMY) weather data update (1978-2008), DNV and NYSERDA defined typical weather as average historical hourly weather from 2010-2020.

1. Preexisting system condition – Evaluators first considered the preexisting heating system age and operating condition by categorizing the event type:
    a. New construction / expansion – If the affected space was newly constructed or significantly renovated, evaluators chose a code-compliant baseline. The system type and heating fuel of the code-compliant system was informed by #3 below as well as New York TRM guidance[7].
    b. Normal replacement – If the preexisting system had failed or aged beyond reasonable repair, evaluators chose a code-compliant baseline as described above.
    c. Retrofit, add-on or early retirement – If the customer chose to replace the heating system while it was still operable and reparable or to supplement the existing system with a heat pump (“add-on”), the pre-existing heating system served as a possible heating baseline for first-year savings considering condition #3.
2. Preexisting system operation, if applicable – If portions of the facility were still heated or cooled by preexisting HVAC systems that met criteria #1c, the evaluators characterized those systems to determine system performance efficiencies and estimated annual heating/cooling load sharing.
3. Facility contact survey and interview – The original web survey and on-site interview gathered information on baseline conditions, including system characteristics and setpoints and customer demographics. These interviews also included questions on what the customer would have chosen for heating and cooling systems absent program intervention. Per New York TRM guidance, customer perspectives on alternative heating decisions are considered in the selection of appropriate site-specific baseline.

3.5.3 Savings Calculation

For the 12 intensive sites in the sample, evaluators conducted an extra site visit to retrieve the heating season data from non-communicating loggers. Such interval data includes true RMS power, temperatures and relative humidities before and after the heating coils, and, in some cases, fan amperage. This data allowed evaluators to compare at each metering interval the installed heat pump system’s power draw with its delivered heating Btu. As heating performance increases with milder outside air temperatures, evaluators created curves that characterize the weather-dependence of each intensive site’s heat pump performance. These performance curves (an example of which is in Section 3.5.1) were synthesized with similar intensive sites, combined with other relevant heat pump performance curve libraries in the Northeast, and applied to all sites in the evaluation sample. All site-specific curves were normalized to reflect manufacturer-rated heating seasonal performance factor (HSPF[8]) at the appropriate design condition.

The evaluation team quantified annual energy impact for each metered heat pump system by comparing the heating loads and performance efficiencies between baseline and as-built conditions. To ensure fair comparison, the evaluators normalized the metered performance data to typical weather conditions at the nearest NOAA weather station. Final, site-specific impact results include savings or penalties and associated RRs by fuel source: electricity, natural gas, and delivered fuels, as applicable.

3.6 Expansion Analysis

The final individual site analysis results were expanded to the sample frame using ratio estimation and a set of sample weights based on the sample design stratification to produce realization rates. Each weight is specific to an individual

[7] https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V8.pdf, page 192.

[8] HSPF is a heating efficiency rating for heat pumps that compares heating output (in Btu) with electric input (in Watt-hour).

stratum and calculated as the number of units in the sample frame (N) for the stratum divided by the number of completed units in the sample (n) for the stratum. The interpretation of the weight is that each completed sample unit represents N/n units in the sample frame.

Notation: The following terms are used in calculating the realization rate for each fuel type:

Tj = Tracking estimate of gross savings for measure j

Vj = Verified estimate of gross savings for measure j

Wj = Weighting factor for measure j used to expand the sample to the population

S = Number of measures in the sample

The realization rates are calculated directly:

$$RR = \frac{\sum_{j=1}^{S} V_j w_j}{\sum_{j=1}^{S} T_j w_j}$$

Relative precision was calculated using the procedures described in Chapter 13 of the California Evaluation Framework.

4 RESULTS

This section presents the heating season impact results of Phase 2 M&V. Results are first presented at the statewide level by overall total MMBtu and by fuel. Next, Phase 2 results are compared with Phase 1 results to assess the reasonableness of the project's initial, at-the-meter analysis. Remaining sections present impact and parameter-level results specific to ASHP and GSHP, as equipment-level M&V enables additional explanatory analysis regarding under- and overperformance compared to expectations.

4.1 Statewide Results

Table 4-1 compares the total site energy savings (MMBtu[9]) for both ASHP and GSHP, with the statewide realization rate. These results incorporate all fuels observed among the 137 sampled projects, including electric, natural gas, oil, propane, wood, and coal.

Relative precision is a normalized measure of uncertainty that is standard in the industry. For realization rates, it expresses uncertainty as a percentage of the verified gross savings (VGS) realization rate. Because the realization rates are low in this study, they dramatically inflate the relative precision and appear to suggest a large amount of uncertainty. Table 4-1 includes the absolute precision as well. It shows the uncertainty in absolute terms as a percentage of 100% VGS realization rate. For example, DNV estimates that the ASHP VGS realization rate is between 17% and 35% (26% ± 9%) with a 90% confidence.

[9] All MMBtu savings in this report reflect *site* MMBtu— i.e., no electric production, transmission, or distribution efficiencies are incorporated.

Table 4-1. Verified Gross Savings by Heat Pump Technology

Technology	N	n*	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate (RR)	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
ASHP	4,045	86	228,373	60,161	26%	±34%	±9%
GSHP†	470	36	44,173	23,198	53%	±14%	±7%
Statewide	4,515	122	272,546	83,821	31%	±25%	±8%

* The sample count for interim heating RR results is lower than the total sample of 137 due to exclusion of 1 site with incomplete heating season data, 6 sites with anomalous operation to be confirmed with customers upon logger retrieval, and 8 Pilot Program sites for which NYSERDA did not claim savings.

† All GSHP sites feature non-wireless loggers to measure loop temperatures to/from the groundwater source; these temperatures significantly influence GSHP performance. Evaluators have not yet retrieved these temperature loggers for most GSHP sites. The presented results reflect the performance of 2 GSHP sites for which groundwater temperature loggers were downloaded and redeployed. Part load efficiency for both units was poor, in part due to low ground water temperatures. Analysts are optimistic that the two sites are not representative of all sites and overall performance will be closer to rated. The GSHP savings would increase to 36,010 MMBtu (82% RR) using seasonal performance factors for NY-specific WaterFurnace GSHP systems. Evaluators anticipate the final GSHP savings to fall between these two extremes.

Table 4-2 illustrates realization rates and relative precisions by fuel type for ASHP, GSHP, and overall. The programs applied identical savings assumptions for all ASHP installations in the evaluation population. One such assumption was that all participating facilities installing ASHPs consumed #2 or #6 fuel oil as the primary heating fuel before ASHP installation. Therefore, the reported fossil fuel savings are exclusively fuel oil for ASHP installations. This assumption greatly skews the calculation of fuel-specific RRs for ASHPs and overall. As a result, many of the tables and figures in this report present total MMBtu (rightmost column) to present the performance results most clearly.

Table 4-2. Realization Rates and Relative Precisions (90% Confidence) by Fuel and by Heat Pump Technology

Technology	n	Electric		Natural Gas		#2 and #6 Fuel Oils		Propane		All Fossil Fuels		Total MMBtu	
		RR	RP	RR	RP	RR	RP	RR	RP	RR	RP	RR	RP
ASHP	86	21%	53%	N/A	N/A	4%	47%	N/A	N/A	24%	39%	26%	34%
GSHP	36	158%	50%	234%	136%	17%	31%	145%	39%	57%	22%	53%	14%
Statewide	122	32%	37%	1594%	156%	6%	32%	220%	37%	29%	29%	31%	25%

ASHP projects realized 21% of electric impacts[10], 24% of fossil fuel impacts, and 26% of overall MMBtu impacts. The primary reason for these low RRs is lower-than-expected heating output from the installed ASHPs, of which over 99% in the evaluation population are DMSHPs.

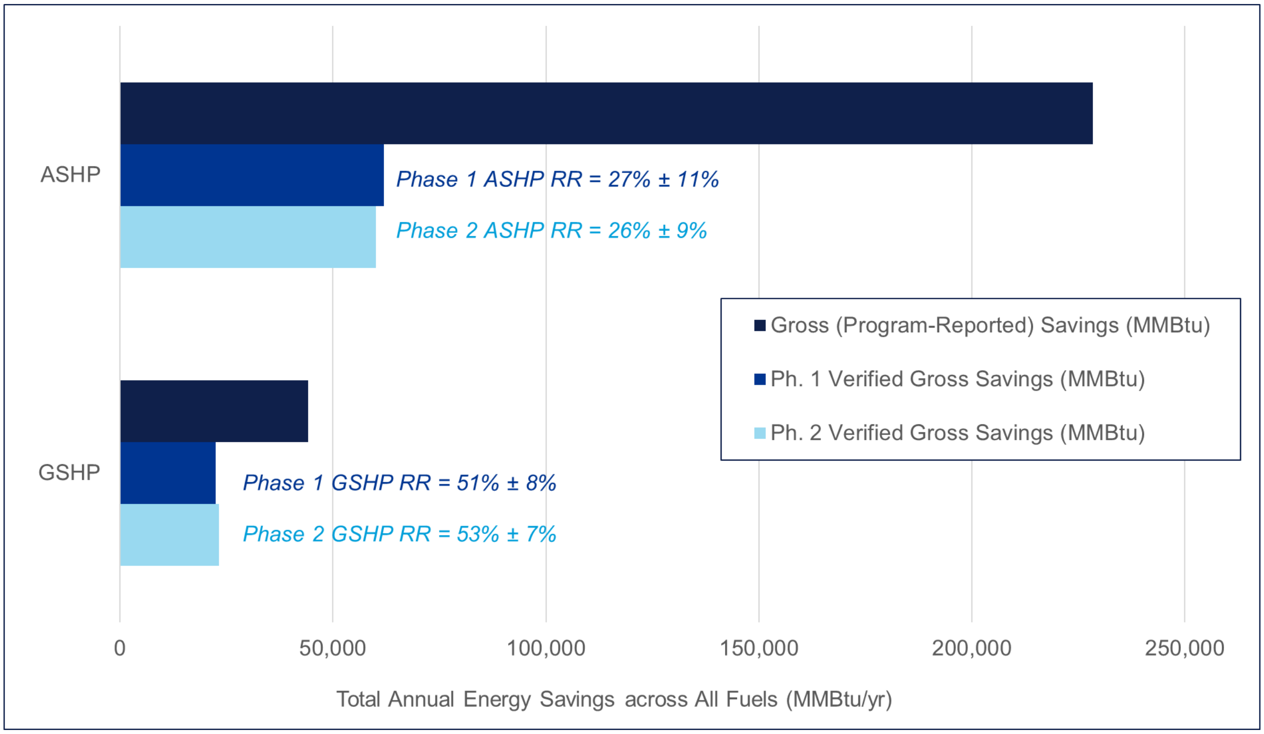
[10] For both ASHP and GSHP systems, the reported and evaluated electric impacts are negative due to the beneficial electrification of the rebated installations. For example, ASHPs resulted in an electric "penalty" 79% lower than predicted by the programs.

GSHP projects realized 158% of electric impacts[11], 57% of fossil fuel impacts, and 53% of overall MMBtu impacts. The primary reasons for the GSHP RRs are lower-than-expected heating output as well as poorer-than-expected heating efficiency, pending the retrieval and analysis of site-specific groundwater loop temperature data.

4.2 Comparison with Evaluation Phase 1

Figure 4-1 illustrates the comparison of total MMBtu impacts between Phase 1 premise-level utility consumption data-based analysis and Phase 2 equipment-level M&V. Evaluated total MMBtu impacts are nearly identical between the two phases, within one RR percentage point for ASHP and two for GSHP installations.

Figure 4-1. Comparison of Evaluation Phase 1 and Phase 2 Results by Heat Pump Technology



As a caveat, evaluators remind the reader that Phase 2 impacts do not yet include cooling season results, whereas Phase 1 impacts represent annual (heating and cooling) impacts. Nonetheless, evaluators are encouraged by the reasonableness of the initial at-the-meter analysis in characterizing the impacts of heat pumps in New York.

Table 4-3 compares Phase 2 and Phase 1 evaluated impacts by fuel type.

[11] GSHPs led to a larger electric penalty than anticipated due to a higher prevalence of fossil fuel-to-GSHP installations than presumed by the program. Specifically, for six projects in the evaluation sample, the program assumed that the GSHPs displaced electric systems (either resistance or HPs) resulting in approximately 32 MWh of reported electric savings. Evaluators determined that these six projects involved GSHPs displacing fossil fuel-fired systems and led to an electric penalty (beneficial electrification) of approximately 65 MWh.

Table 4-3. Comparison of Evaluation Phase 1 and Phase 2 Impacts by Fuel

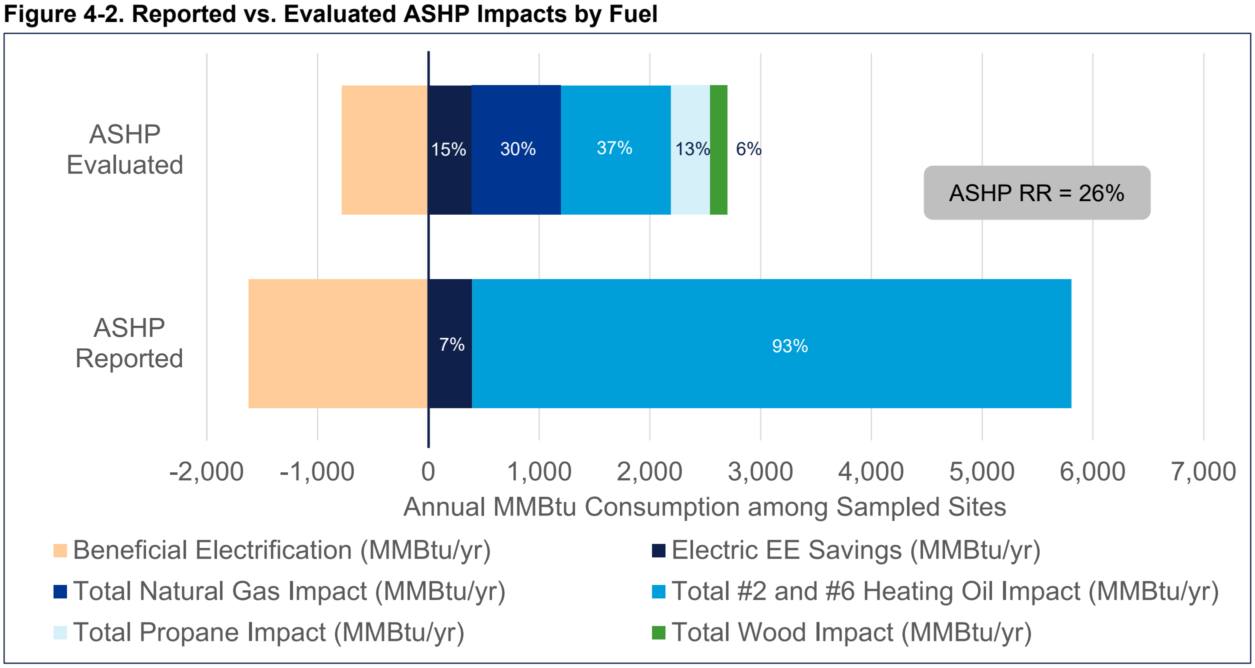
Technology	n	Evaluation Phase 2 Impacts / Phase 1 Impacts					
		Electric	Natural Gas	Fuel Oils	Propane	All Fossil Fuels	Total MMBtu
ASHP	37	115%	240%	59%	109%	123%	125%
GSHP	15	428%	80%	58%	211%	117%	80%
Statewide	52	293%	174%	59%	161%	121%	106%

Evaluators determined similar fossil fuel and total MMBtu impacts between the two phases for both ASHPs and GSHPs. Notably, we determined significantly higher Phase 2 GSHP electric impacts than in Phase 1, primarily due to two sampled projects that demonstrated electric savings in Phase 1 but were confirmed in Phase 2 to have displaced fossil fuel systems exclusively, leading to electric penalties.

4.3 ASHP Results

Figure 4-2 illustrates the impacts by fuel for ASHP installations. As the program did not claim savings among natural gas, propane, or wood fuels, evaluators cannot expand the ASHP impact results from the sample to the population[12]. Figure 4-2 presents impacts among the sample of 86 ASHP projects included in the interim heating analysis without sampling weights applied. Nonetheless, the figure illustrates that ASHP installations offset a broader diversity of fuels as compared with the programs' oil assumption.

Figure 4-2. Reported vs. Evaluated ASHP Impacts by Fuel



[12] Appendix B includes an alternative to Figure 3-2 (Figure B-5) that uses the tracked preexisting fuel type as a means of expansion of ASHP results back to the full population. Figure B-5 hypothetically presumes that the program claimed the appropriate fossil fuel savings based on tracked fuel type.

Overall, evaluators determined lower fossil fuel offset—and, in turn, lower beneficial electrification—than assumed by the program. Offset fossil fuels are distributed among natural gas (30%), fuel oils (37%), propane (13%), and wood (6%). Additionally, electric-to-electric installations, either from installations displacing electric resistance heating or invoking code-compliant heat pumps as baseline, accounted for the remaining 15% of total MMBtu savings. Comparatively, the programs' savings assumptions reflected an assumed 25% share of electric-to-electric installations that led to 7% of the total claimed MMBtu.

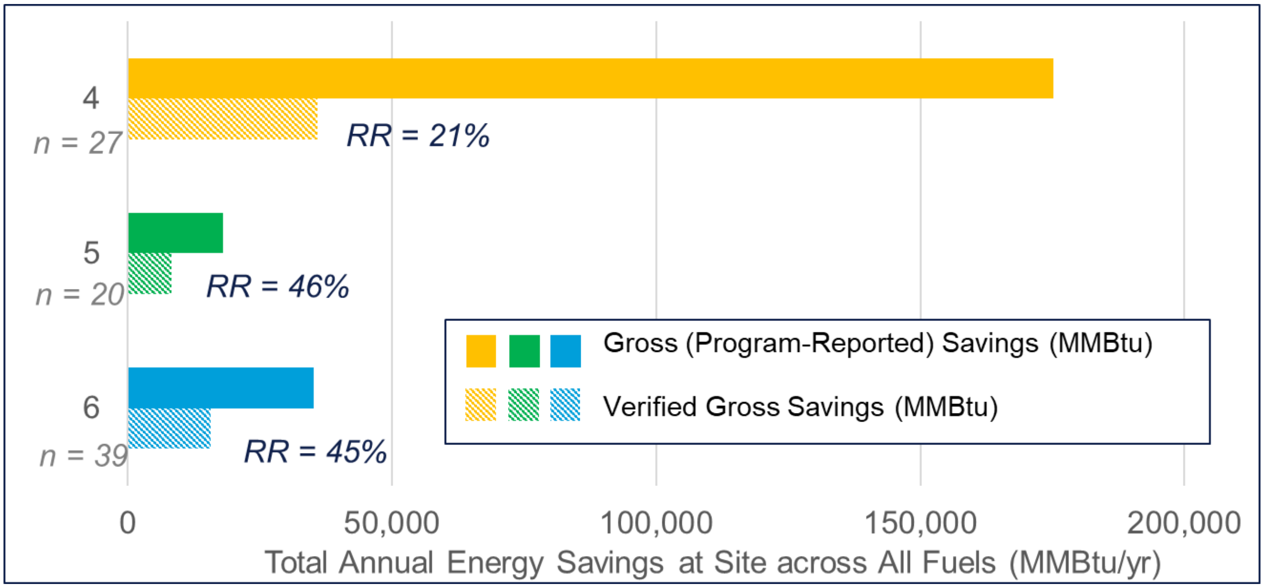
Evaluators compared the performance of ducted ASHPs and ductless mini-split ASHPs (DMSHPs), as shown in Table 4-4. While evaluators attempted to include as many ducted ASHP projects in the evaluation as possible, only 3 of the 12 ducted ASHPs were evaluated, leading to comparatively poor precision in results. DMSHPs realized, on average, about twice as much claimed MMBtu savings per project than ducted ASHPs.

Table 4-4. ASHP Results by System Type

System Type	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
ASHP Ducted	12	3	297	44	15%	±115%	±17%
ASHP Ductless	4,033	83	227,996	60,809	27%	±35%	±9%
Total ASHP	4,045	86	228,373	60,161	26%	±34%	±9%

Figure 4-3 illustrates ASHP performance by climate zone, per the designations illustrated in Figure 3-1. Upstate climates (5 and 6) performed similarly, with each significantly outperforming the downstate climate zone 4. Climate zones 5 and 6 are colder climates, leading to more opportunity for ASHP savings. Additionally, evaluators hypothesize that downstate installations are more likely to be used for cooling only and not offset the existing heating system. This hypothesis will be further investigated in the upcoming cooling season analysis.

Figure 4-3. ASHP Results by Climate Zone

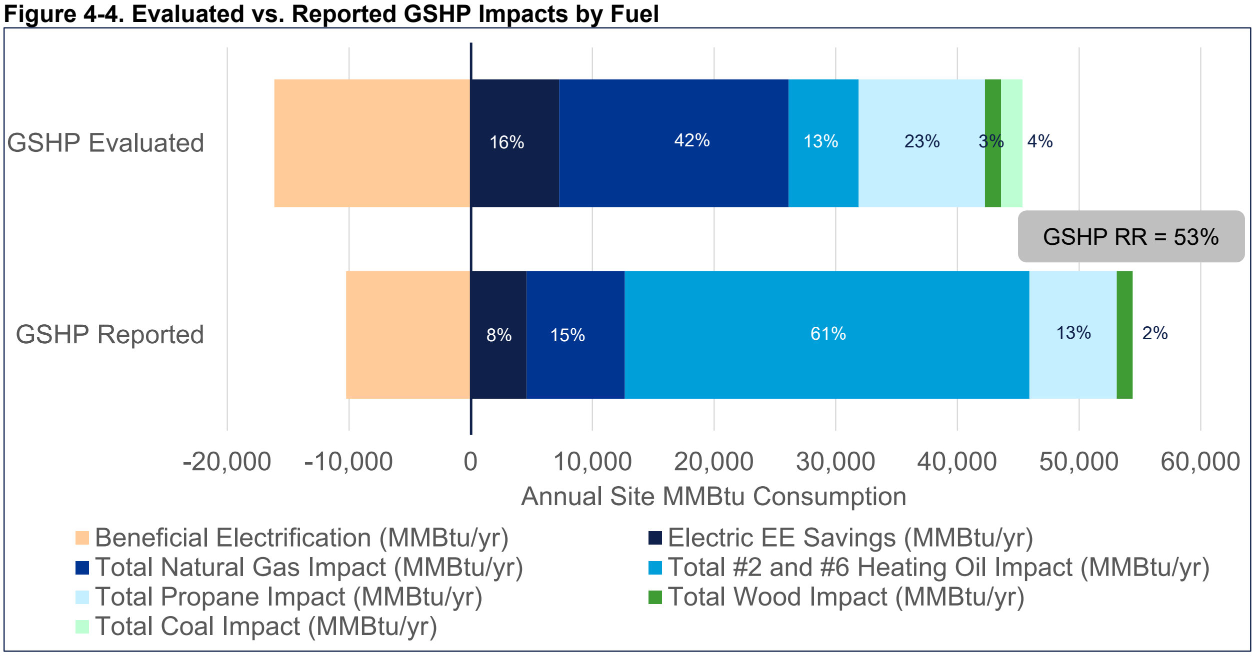


4.4 GSHP Results

Evaluators remind the reader that the GSHP impacts are currently preliminary, as the groundwater loop temperature logger data is still pending for 38 of the 40 sampled projects. Nonetheless, we present preliminary heating impacts based on the operational data of all sampled projects paired with the performance data of two intensive projects.

Figure 4-4 illustrates the impacts by fuel for GSHP installations. Unlike for ASHP, the programs claimed fossil fuel savings among natural gas, fuel oils, propane, and wood categories. This allowed evaluators to expand results by fuel from the sample to the population of 470 GSHP projects.

Figure 4-4. Evaluated vs. Reported GSHP Impacts by Fuel



Evaluators determined different GSHP fuel savings shares than assumed by the programs. Natural gas accounted for 42% of evaluated MMBtu savings, as compared with the program's assumption of 15%. On the other hand, oil accounted for 13% of evaluated MMBtu savings but 61% of the program's savings claim. Evaluators also determined that coal was the primary preexisting heating fuel for one of the projects in the sample.

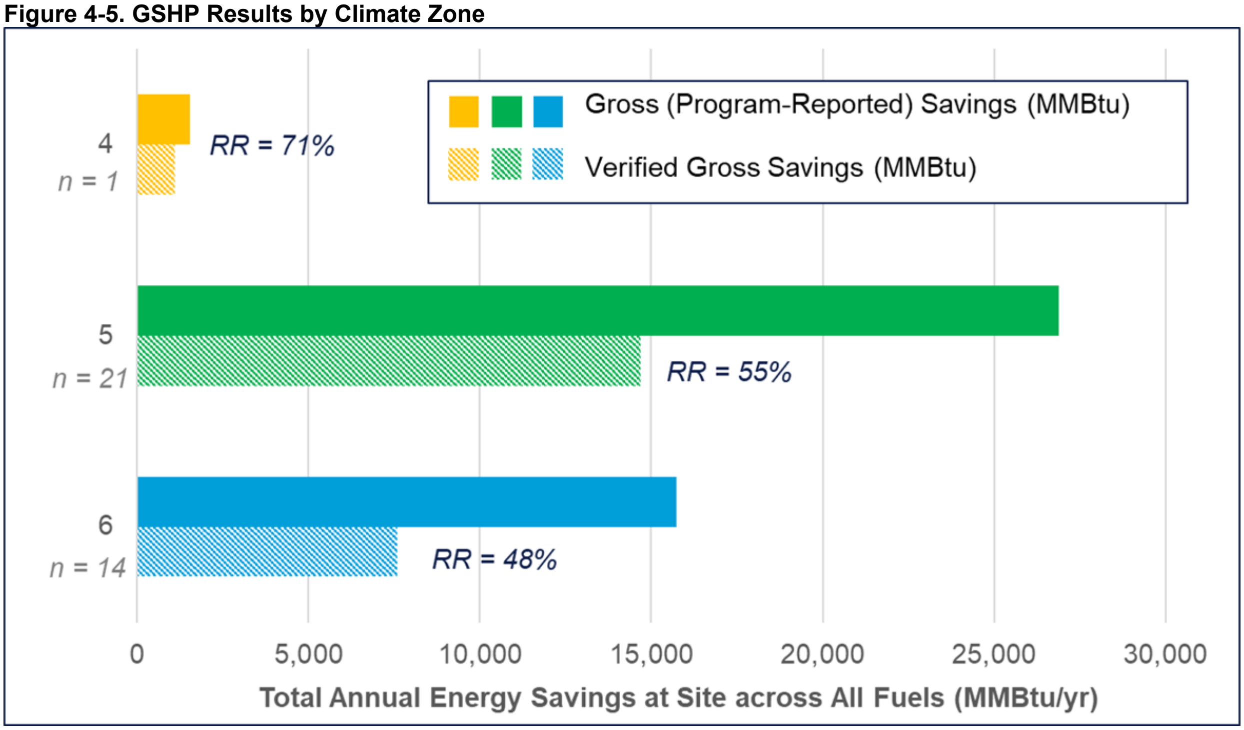
Table 4-5 compares the performance of GSHP projects between commercial and residential sectors, as classified in program tracking data. We found similar performance between sectors and overall.

Table 4-5. GSHP Results by Sector

Customer Type	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Commercial	19	5	4,541	2,423	53%	±15%	±8%
Single-Family Residential	447	31	37,533	19,624	52%	±18%	±9%
Total GSHP	466	36	42,073	22,095	53%	±14%	±7%

Figure 4-5 compares the performance of GSHP projects by climate zone, illustrating similar realization rates between the upstate climate zones. Climate zone 4 only featured one installation in the sample.

Figure 4-5. GSHP Results by Climate Zone



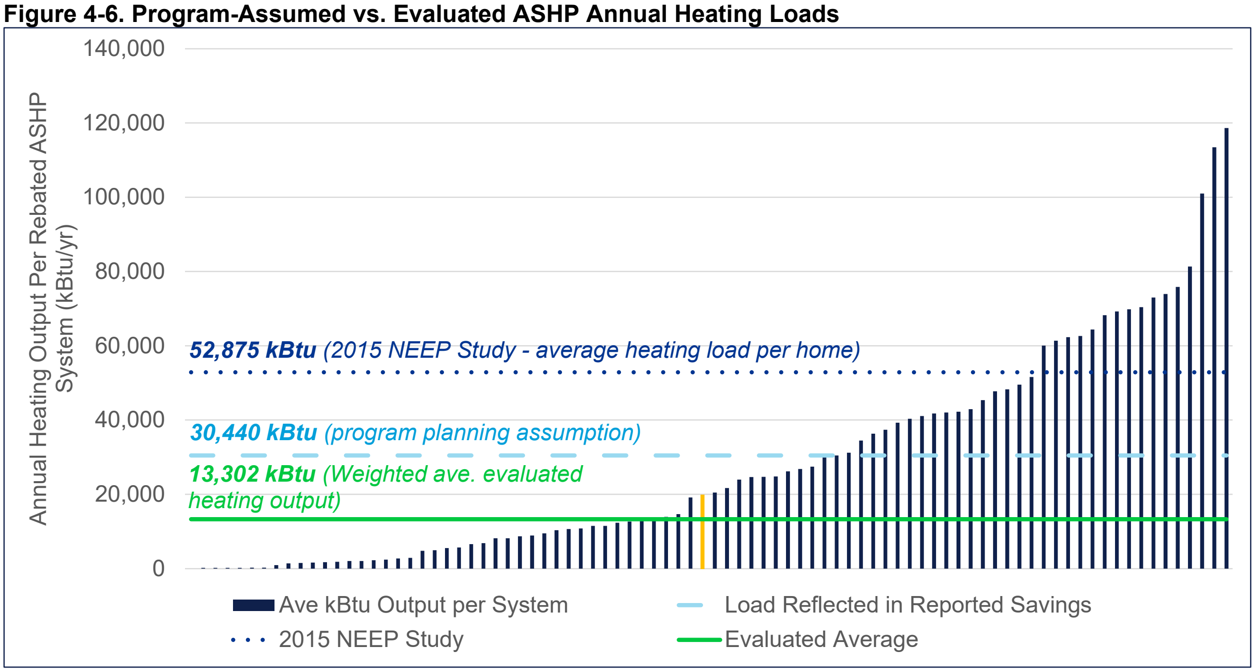
4.5 Parameter Analysis

Evaluators examined system-level metered data more closely to quantify relevant operating parameters such as heating load, full-load hours, and heating seasonal performance factor (HSPF) for both ASHP and GSHP systems. This analysis helps reveal why HP systems in aggregate underperformed compared to expectations. Additional results are presented in Appendix B.

4.5.1 ASHP Parameters

Evaluators determined that the rebated ASHPs, on average, satisfy an annual heating load that is 44% of that predicted by the program, as illustrated in Figure 4-6. Program-reported savings are based on a 2015 NEEP study that estimated whole-home heating consumption for single-family residences with oil heating.[13] The program reduced this value with a 66% multiplicative factor to account for anticipated shares of displacement vs. replacement projects. Program savings also reflect an assumed 75% / 25% distribution between pre-existing oil-fired and electric resistance heating systems, respectively. Notably, program-reported savings are identical for all ASHPs, whether ducted or ductless, and claim only heating season impacts. If one accepts the NEEP whole home annual heat load estimate as correct, this study found that rebated ASHPs are meeting 29% (44% x 66%) of the home heating load on average.

Figure 4-6. Program-Assumed vs. Evaluated ASHP Annual Heating Loads

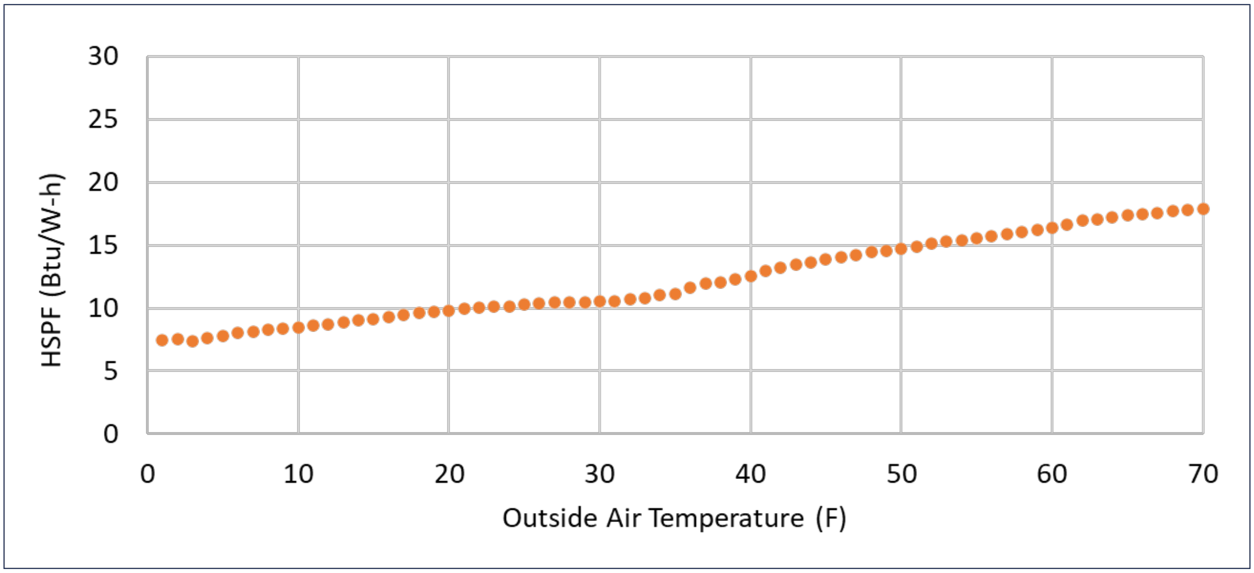


Evaluators primarily attribute the 26% MMBtu RR for ASHPs to the 44% heating output finding. Since over 99% of ASHPs in the evaluation population are DMSHPs, the program overestimated ASHP operating hours by using a whole-home heating load as a starting point in the savings assumption. Use of total installed capacity (with assumed annual full-load operating hours) would more accurately represent the best-case annual heating output of the installed DMSHP systems. By pairing the metered operation with rated capacities by ASHP system, evaluators determined **549 annual full-load heating hours**.

[13] For the whole-home heating consumption value, the NEEP study referenced the Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS) database, filtered for residences in the Northeast: "Table CE4.7 Household Site End-Use Consumption by Fuel in the Northeast Region, Averages, 2009," http://www.eia.gov/consumption/residential/data/2009/c&e/enduse/xls/CE4.7%20Average%20Site%20EndUse%20Consumption%20by%20Fuel%20in%20Btu_Northeast.xlsx.

Through analysis of eight intensive ASHP sites in the sample, we found that rebated ASHPs generally operate near rated efficiency levels. The industry-standard heating efficiency rating for ASHPs is HSPF, which reflects a weighted-average efficiency that encapsulates different seasonal performance levels for a given climate. An ASHP providing heat at 40°F will achieve a higher efficiency than the same ASHP providing heat at 10°F, as illustrated by an example HSPF vs. outside air temperature (OAT) curve in Figure 4-7.

Figure 4-7. Example ASHP Performance vs. Outside Air Temperature Curve



Evaluators determined that the rebated ASHPs achieved an overall, weighted-average HSPF[14] 3% lower than the weighted-average rated HSPF, as shown in Table 4-6. Both rated and achieved HSPFs are significantly higher than the 8.5 HSPF reflected within the program-assumed heating load shown in Figure 4-6.

Table 4-6. Evaluated vs. Program-Assumed HSPF for ASHPs

Installation Type	Weighted Average HSPF		
	Program-Assumed	Rated	Evaluated
ASHP	8.53	11.66	11.37

The evaluated HSPF of 11.4 corresponds to a coefficient of performance of 3.3, indicating that ASHPs can satisfy the same heating loads as code-compliant fossil fuel-fired systems with 75% fewer input Btu. From an efficiency standpoint, the rebated ASHPs performed well; however, based on Figure 4-6, the ASHPs operate less—and have fewer opportunities for savings—than assumed by the programs.

Another notable contributor to the ASHP MMBtu RR is baseline. As described above, the programs assumed that all rebated ASHPs replace an assumed blend of oil-fired heating systems (with an assumed coefficient of performance[15] of 0.75) and electric-resistance heating systems (COP = 1). Evaluators determined that 17 of the 97 sampled ASHPs featured an ASHP baseline that, as shown in Table 3-6, operate with a COP of approximately 3 or higher. Evaluators determined ASHP to be

[14] System-specific HSPFs were averaged together using weights defined by rated heating capacities.

[15] Coefficient of performance (COP) is a unitless efficiency metric for an HVAC system, defined as the ratio of Btu output (i.e., delivered heating or cooling Btu) with Btu input (i.e., the power draw of the HVAC system). COP is converted to HSPF through multiplication with a conversion factor of 3.412 Btu/Watt.

baseline for these 17 sites because it either represented the pre-existing heating system or was the customer's self-reported heating system preference absent the program. From a COP perspective, ASHP-to-ASHP projects limit the amount of achievable savings, as high-efficiency ASHPs achieve only an incremental COP increase (less than 1 COP point), while fossil fuel-to-ASHP projects achieve a significantly higher increase of 2+ COP points. Evaluators estimate that these 17 projects led to a 10% decrease in MMBtu RR.

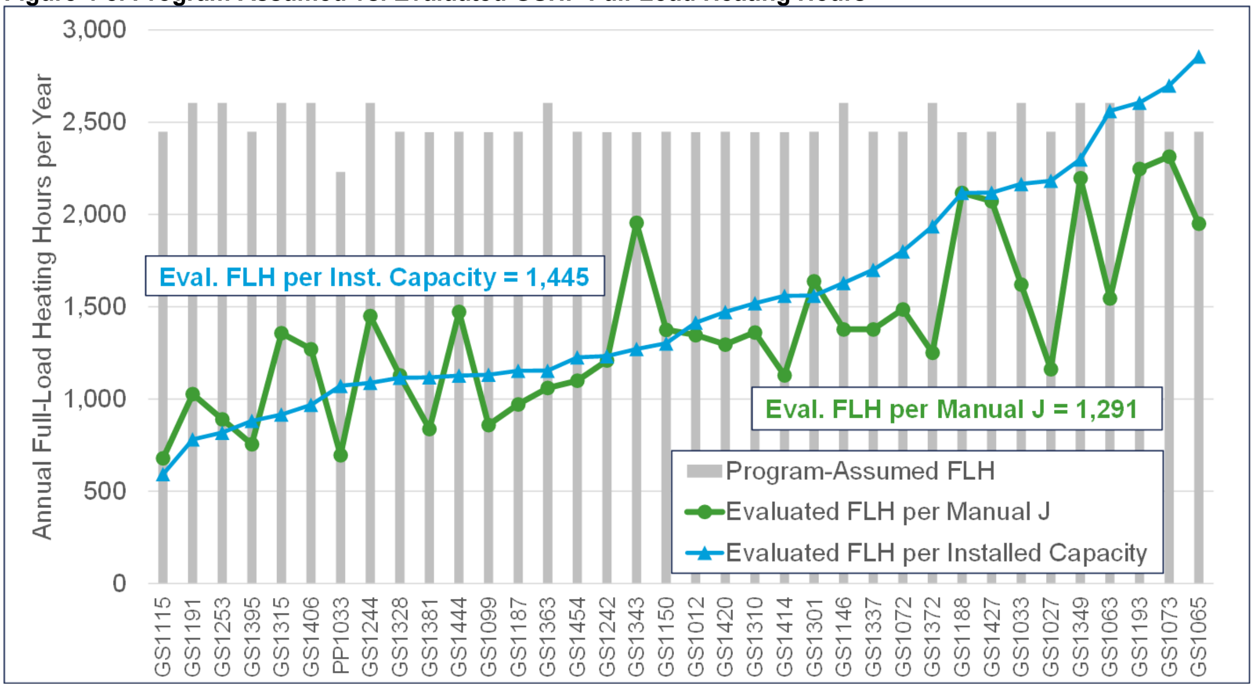
Evaluators paired survey responses with metered results to examine other factors that could affect savings and found:

- The **current usage of preexisting heating systems** is a determinant of heat pump performance, as illustrated in Appendix B's Figure B-2. Customers self-reporting to no longer use the preexisting heat system had HPs that significantly outperformed (55% MMBtu RR) those of customers who said they use it frequently (23% RR) or infrequently (25% RR).
- MMBtu results vary by **preexisting heating fuel**, with electricity (MMBtu RR of 51%), oil (RR of 54%), and propane (RR of 43%) outperforming natural gas (RR of 19%), as illustrated in Figure B-6. Evaluators hypothesize that the natural gas systems were more likely to remain in use and to be used more frequently than other fuel systems.
- **Multi-split** ductless projects (i.e., DMSHPs with multiple heads) performed slightly better (29% MMBtu RR) than single-head DMSHPs (21% MMBtu RR). However, we found the heating run-hours of multi-head and single-head DMSHPs to be similar, indicating that the MMBtu RR difference may be driven by the higher prevalence of single-head DMSHPs in the downstate region.
- **Tracked conditioned square footage** was a noticeable driver of ASHP MMBtu RR, as illustrated in Figure B-7. ASHP installations associated with less than 1,500 square feet of tracked conditioned area performed significantly better (MMBtu RRs between 64% and 96%) than those associated with 4,000 square feet or less (RRs between 3% and 30%).
- **Controls for ducted ASHPs** can be more optimally programmed. While ducted ASHPs constituted only 4 of the 97 sampled ASHP projects, evaluators found that the controls for 2 ducted ASHP systems were not optimized. We observed the backup electric resistance heat initiated at significantly higher outside air temperatures than necessary. In one case, our power loggers showed backup heat at temperatures of 40°F.
- **Repair history** does not correlate with MMBtu savings. 23 of the 137 customers in the Phase 2 sample indicated in the Phase 1 survey that their heat pump(s) required some level of repair or replacement of parts. The MMBtu RR for these customers is nearly identical to that of the 112 customers who did not require heat pump repair. 2 customers did not know the repair status of their heat pumps.
- Savings slightly varied for customers with and without **heat pump controls integrated** with that of other heating systems. Only 4 customers in the Phase 2 sample self-reported having the heat pump controls integrated with another heating system's. These 4 customers' heat pumps performed slightly worse (37% MMBtu RR, unweighted) than those of the 42 customers that share the heating load with another heating system but without integrated controls (49% MMBtu RR, unweighted). Evaluators suspect that low sample size is the primary driver of this difference.

4.5.2 GSHP Parameters

Evaluators determined, on average, that GSHPs operate for 55% of the hours per year assumed within the program's savings calculator. Figure 4-8 compares the annual full-load heating hours values among the program assumptions (vertical grey bars), evaluation metering full-load hours (FLH) as defined by installed capacity (blue line), and evaluated FLH as defined by Manual J heating load values estimated by participating contractors (green line). Results are ordered from lowest evaluation $FLH_{capacity}$ to highest. Only two of the 36 sampled sites had $FLH_{capacity}$ exceed the program assumption.

Figure 4-8. Program-Assumed vs. Evaluated GSHP Full-Load Heating Hours



We observe similar correlation between $FLH_{capacity}$ and $FLH_{ManualJ}$ in Figure 4-8, indicating that contractors are generally right-sizing the GSHP systems at or slightly above the building's Manual J heating load. Nonetheless, the 53% MMBtu RR for GSHPs is primarily attributable to significantly fewer heating FLH than assumed by the program. The program's assumed heating FLH range from 2,230 (NYC) to 2,604 (Binghamton). As a point of comparison, Appendix G of the NY TRM Version 8 recommends heating FLHs no higher than 1,125 for heating systems within single-family detached residences of "old" vintage classification. Evaluators are unsure of the source of FLHs within the GSHP savings calculator[16] but believe them to be significantly overestimated compared to current NY TRM recommendations.

From a heating efficiency perspective, GSHP systems generally underperformed as compared with AHRI-rated efficiencies. Table 4-7 illustrates the weighted-average evaluated efficiency as compared with AHRI ratings and program assumptions.

Table 4-7. Evaluated vs. Program-Assumed HSPFs for GSHPs

Installation Type	Weighted Average HSPF		
	Program-Assumed	Rated	Evaluated
GSHP	13.77	12.50*	9.25†

* The rated GSHP value is not comprehensive of the whole heating season like HSPF; rather, it reflects full-load performance at a specific test condition.

† Pending site-specific loop temperatures and performance. This value currently reflects measured performance at 2 intensive sites, one of which involves a horizontal groundwater loop that exhibited very low return water temperatures and subsequently poor efficiency.

[16] The program's GSHP Savings Calculator suggests that the full load hours were derived from Manual J using design load values at design conditions among five weather regions: Albany, Binghamton, Massena, New York City, and Rochester.

While lower FLH and poorer efficiency are the primary reasons behind the 53% MMBtu RR for GSHPs, evaluators paired the survey responses with metered results and observed two additional drivers:

- **Tracked conditioned square footage** is a key driver of GSHP savings, though differently than for ASHPs. As shown in Table B-11, higher tracked conditioned square footage generally correlates with higher GSHP MMBtu savings. Most of the GSHP projects in the sample involve whole-home systems, though a small number of partial-home systems led to lower savings likely due to load-sharing with other heating systems.
- **Preexisting heating system type** is another determinant of GSHP savings, as shown in Table B-10, with heat pump (MMBtu RR of 131%, n=3) outperforming forced air (RR of 40%, n=17) and boiler (RR of 48%, n=2). GSHPs replacing preexisting HPs operated more frequently than GSHPs replacing fossil fuel systems, though low sample size is a consideration.

Evaluators will refresh the GSHP impacts and performance metrics with site-specific groundwater loop temperature data as those loggers are retrieved in Fall 2021.

5 INTERIM FINDINGS AND UPCOMING RESEARCH

This interim memo shares the heating season impact results as part of the NYSERDA Heat Pump Evaluation Phase 2 M&V activities. Below are eight key takeaways followed by a summary of upcoming related research.

1. The Underutilized Products, Heat Pumps and Solar Thermal, and the Heat Pump Pilot Projects Demonstration programs led to significant MMBtu savings and offsets of fossil fuels, including 128,329 MMBtu of natural gas, 135,451 gallons of oil, and 172,740 gallons of propane. However, program-rebated installations led to significantly reduced evaluated savings as compared with program-reported values. Across all fuel sources, including electricity, ASHPs realized 26% of program-reported MMBtu savings, while GSHPs realized 53% of program-reported MMBtu.

2. Phase 2 evaluation results—the focus of this memo—correlated closely with results from evaluation Phase 1, which involved at-the-meter analysis of 239 projects. We found that Phase 2 MMBtu RRs were within 1-2% of Phase 1 MMBtu RRs for both ASHPs and GSHPs. However, Phase 1 impacts include both heating and cooling season savings, whereas Phase 2 currently addresses the heating season only. We expect the two phases' results to begin to deviate as Phase 2 cooling season impacts are quantified. Nonetheless, we are encouraged that at-the-meter analysis proved a reasonable first step to quantifying savings of heat pump installations.

3. Quantifying evaluated savings by fuel proved difficult for ASHP installations, as the program claimed all fossil fuel savings as oil, limiting the evaluators' ability to expand evaluation results from the sample to the population of projects. Among 93 ASHP projects in the evaluation sample, we found that program-rebated installations led to a diversity of savings by fuel, including natural gas (comprising 30% of total MMBtu savings across all fuels), fuel oils (37%), propane (13%), and wood (6%).

4. The program claimed a broader diversity of fuel-specific savings for GSHPs, though evaluators determined higher shares of natural gas and propane, and lower shares of fuel oils, than claimed.

5. Evaluators examined overall, ASHP, and GSHP results among a variety of segments of interest. Appendix B includes several such figures. For example, ASHP projects performed significantly better in upstate climate zones 5 and 6 as compared with downstate climate zone 4. We did not observe such differences for GSHP results by climate zone.

6. The primary driver of the 26% MMBtu RR for ASHPs is less frequent operation than assumed within program savings claims. The programs claimed identical savings values per ASHP installation regardless of system type (ducted vs. ductless), climate zone, or facility type. Savings claims reflected oil offsets based on whole-home NEEP research, derated to account for displacement vs. replacement projects and an assumed 25% share of electric-to-HP projects. Evaluators determined that ASHPs provide 56% lower annual heating output than reflected within program savings claims. Phase 2 metered data, extrapolated over a full year and correlated with installed equipment capacities, led to 549 average annual full-load heating hours across the ASHP sample. In the context of the current New York TRM[17] heat pump savings algorithm, evaluated ASHP projects demonstrated a sizing ratio of approximately 0.3 on average as compared to a typical whole-home heating load.
7. Overall, ASHPs performed closely to rated efficiencies, achieving a weighted average heating seasonal performance factor (HSPF) of 11.37. This efficiency value means that, for every 4 Btu required by a code-compliant fossil fuel-fired system to heat a given space, the ASHP can heat the same space with 1 Btu.
8. The primary drivers of the 53% MMBtu RR for GSHPs are: 1) fewer annual full-load heating hours than assumed in the program's savings calculator, and 2) poorer-than-rated achieved efficiencies. Evaluators determined weighted average FLHs of 1,445 (per installed capacity) or 1,291 (per tracked Manual J building heating load), whereas the program's savings calculator featured FLHs ranging from 2,230 to 2,604. The weighted-average HSPF across 36 sampled GSHP projects is currently 9.3, as compared with weighted-average AHRI rating of 12.5. Efficiency results are expected to change as evaluators retrieve the groundwater loop temperature loggers at each sampled project.

5.1 Upcoming Research

The evaluation team is currently in the process of remotely collecting and analyzing cooling season operation data. We expect the loggers to remain in the field through the summer, with earliest retrievals occurring in September. DNV engineers will then update each site-specific analysis with cooling season metered data and observed weather conditions. Cooling season impact results will be fully developed in November 2021, with the evaluation final report drafted and presented in December 2021.

In parallel with this study, DNV is launching the Statewide Heat Pump Technical Study in coordination with the New York DPS, joint utilities, and NYSERDA. Our project teams are investigating the use of this study's metered data to bolster the statewide dataset. To supplement this study's data, DNV will deploy M&V equipment among a sample of Clean Heat Program participants in Fall 2021.

[17] Version 8 at the time of this writing, https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V8.pdf

APPENDIX A: DETAILED PHASE 2 ANALYSIS METHODS

Figures A-1 and A-2 illustrate additional details on evaluation analysis methods.

Figure A-1. Heat Pump Post-Installation Model Creation

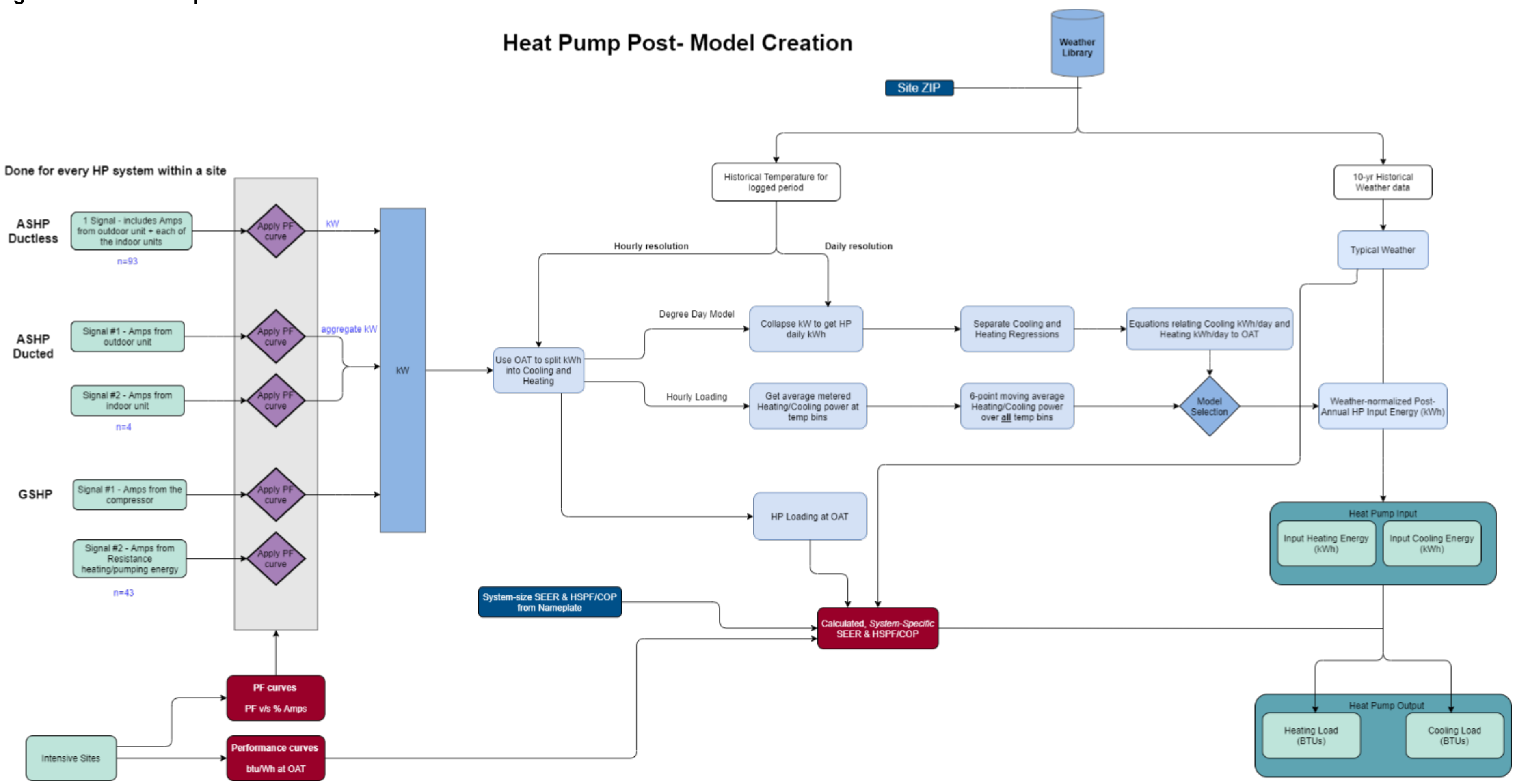
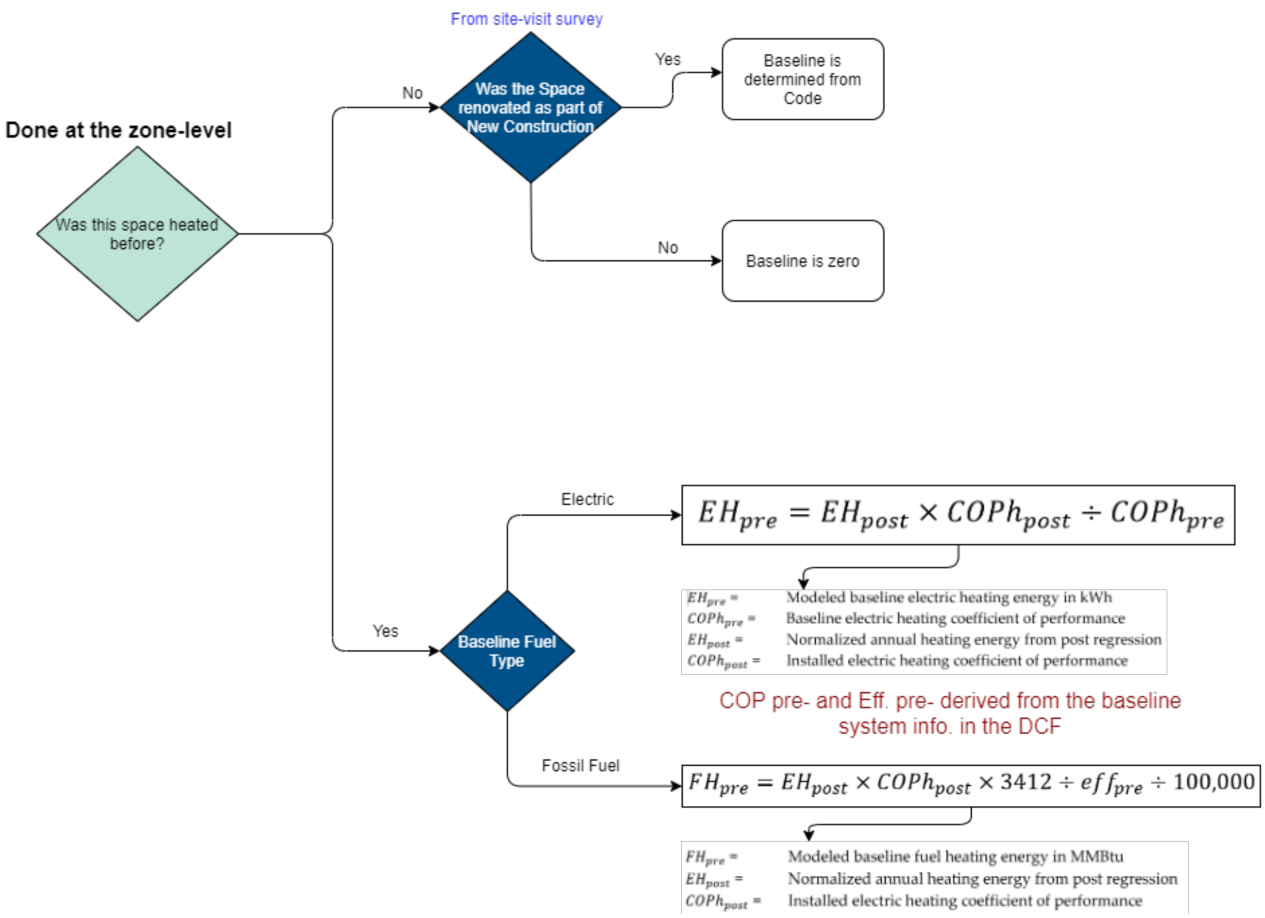


Figure A-2. Heat Pump Heating Baseline Determination Decision Tree



APPENDIX B: ADDITIONAL RESULTS

This appendix contains additional tables and figures that characterize the performance of program-sponsored heat pump installations.

B.1 Statewide Results

Table B-1. Statewide Results by Customer Sector

Customer Type	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Commercial	19	5	4,541	2,423	0.53	15%	8%
Multifamily	627	3	57,448	17,351	0.30	115%	35%
Single-Family Residential	3,869	114	210,558	62,965	0.30	27%	8%
Statewide Total	4,515	122	272,546	83,821	0.31	25%	8%

Table B-2. Statewide Results by Equipment Type

System Type	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
ASHP Ducted	10	3	297	44	0.15	115%	17%
ASHP Ductless	4,033	83	227,996	60,809	0.27	35%	9%
GSHP	470	36	44,173	23,198	0.53	14%	7%
Statewide Total	4,513	122	272,465	83,796	0.31	25%	8%

Table B-3. Statewide Results by Tracked Preexisting Heating Fuel Type

Preexisting Heating Fuel	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Electricity	369	19	40,618	35,012	0.86	33%	28%
Natural gas	3,125	34	159,806	31,083	0.19	54%	10%
Propane	205	16	14,607	6,374	0.44	25%	11%
Oil	603	39	37,633	18,618	0.49	24%	12%
Other	171	13	17,565	7,379	0.42	28%	12%
Wood	42	1	2,317	3,879	1.67	0%	0%
Statewide Total	4,515	122	272,546	83,821	0.31	25%	8%

Table B-4. Statewide Results by Tracked Preexisting Heating System Type

Preexisting Heating System	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Electric Resistance	116	5	7,786	1,758	0.23	113%	26%
Fireplace/stove	36	3	1,376	956	0.69	58%	40%
Forced Air	1,836	47	107,291	39,802	0.37	44%	16%
Heat Pump	306	13	34,360	19,200	0.56	41%	23%
Hydronic Boiler	1,618	29	82,637	16,501	0.20	79%	16%
Other	441	21	33,915	9,647	0.28	54%	15%
Steam Radiator	119	4	5,181	718	0.14	110%	15%
Statewide Total	4,353	118	267,365	82,228	0.31	25%	8%

Table B-5. Statewide Results by Region

Region	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Albany	190	18	9,439	4,877	0.52	44%	23%
Binghamton	192	13	11,512	8,347	0.73	34%	24%
Buffalo	240	12	19,472	10,522	0.54	21%	12%
NYC	2,998	25	176,427	35,550	0.20	55%	11%
Poughkeepsie	699	42	41,157	16,252	0.39	28%	11%
Syracuse	180	12	13,794	6,809	0.49	31%	15%
Statewide Total	4,499	122	271,800	83,592	0.31	25%	8%

Table B-6. Statewide Results by Electric Utility

Electric Utility	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Central Hudson Gas & Electric	604	36	37,173	14,618	0.39	30%	12%
Consolidated Edison	2,885	28	173,809	35,552	0.20	53%	11%
National Grid	411	28	30,726	16,184	0.53	26%	13%
New York State Electric and Gas	376	22	22,162	11,636	0.53	31%	16%
Orange and Rockland	58	1	1,835	363	0.20	0%	0%
Rochester Gas and Electric	94	7	5,508	4,589	0.83	58%	48%
Statewide Total	4,428	115	265,706	81,717	0.31	25%	8%

Table B-7. Statewide Results by Tracked Square Footage Affected by the Heat Pump Installation

Tracked Conditioned Space	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Less than 1,000 square feet	210	3	10,165	9,726	0.96	42%	40%
1,000 to less than 1,500 square feet	815	18	37,175	23,763	0.64	44%	28%
1,500 to less than 2,000 square feet	1,125	31	57,846	16,317	0.28	40%	11%
2,000 to less than 2,500 square feet	921	27	51,638	7,607	0.15	49%	7%
2,500 to less than 3,000 square feet	473	15	26,942	4,259	0.16	72%	11%
3,000 to less than 4,000 square feet	517	11	35,894	10,404	0.29	44%	13%
4,000 or more square feet	423	17	46,707	32,674	0.70	37%	26%
Statewide Total	4,484	105	266,366	81,920	0.31	25%	8%

Figure B-1. Statewide Results by Customer's Survey Response on Preexisting Heating System Type

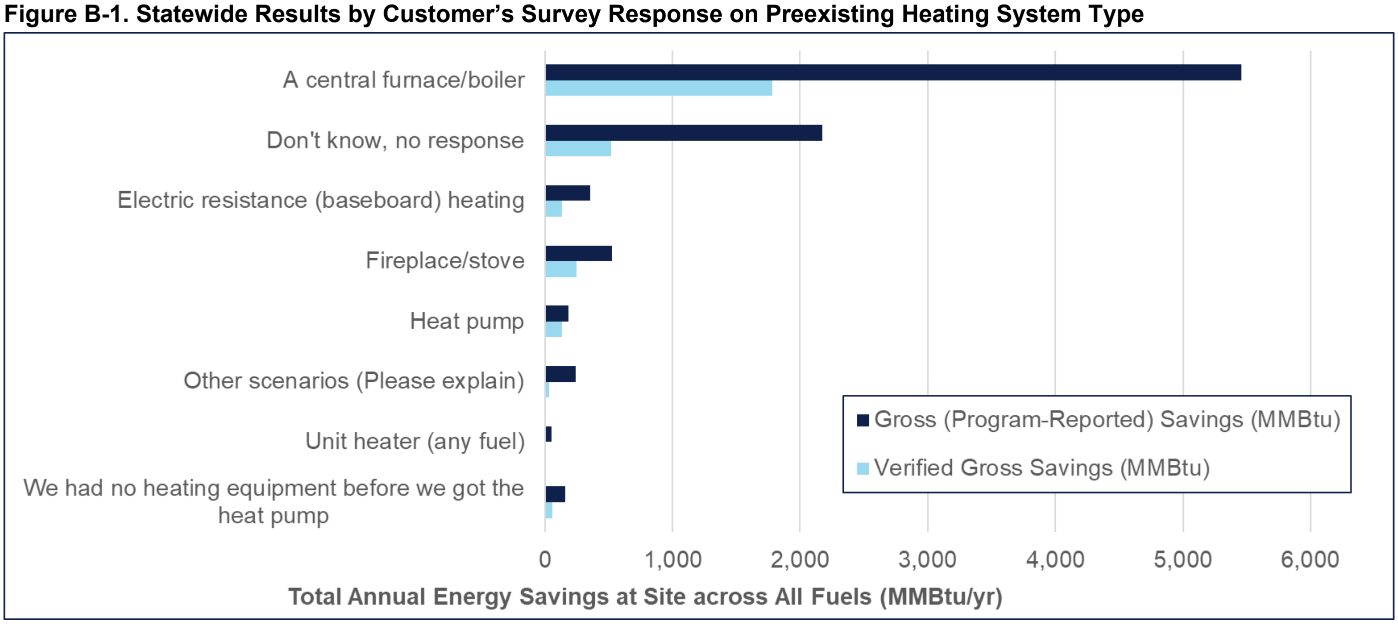


Figure B-2. Statewide Results by Customer Response on Current Usage of the Preexisting Heating System

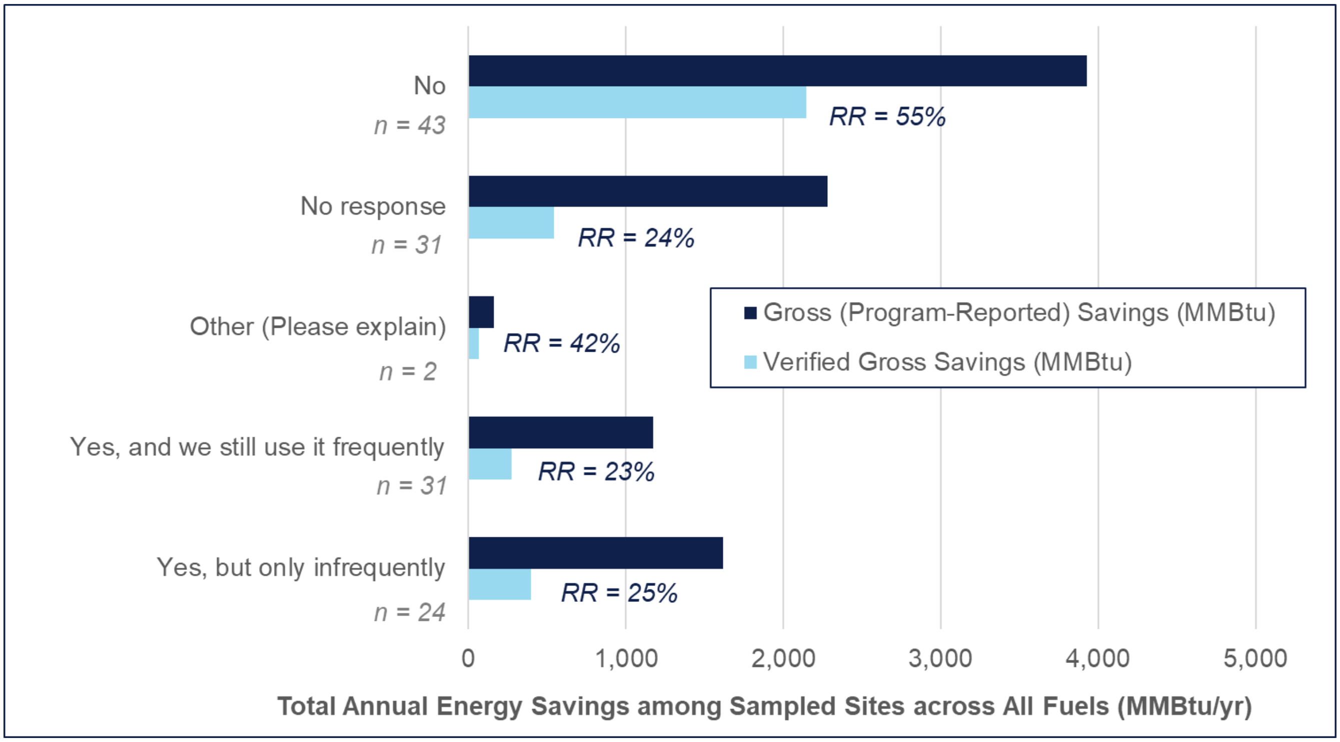


Figure B-3. Statewide Results by Evaluator's Classification of Project Baseline

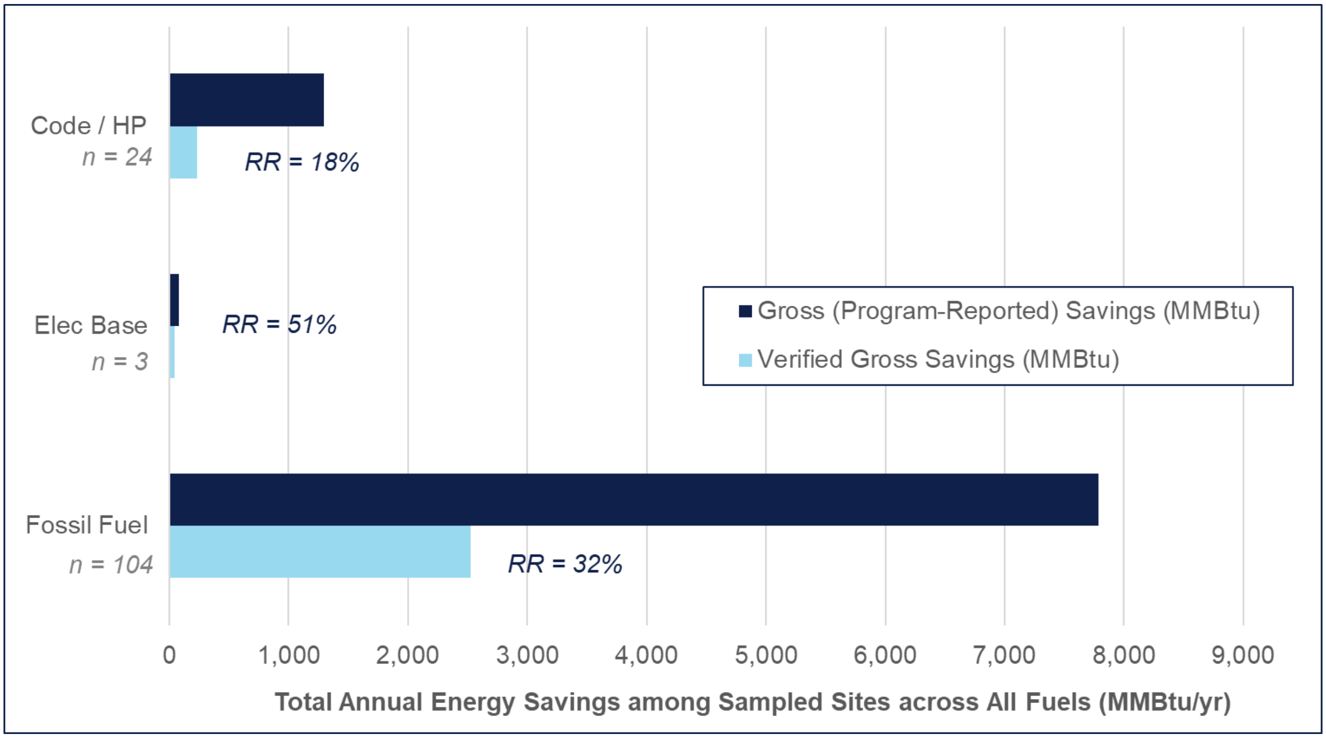
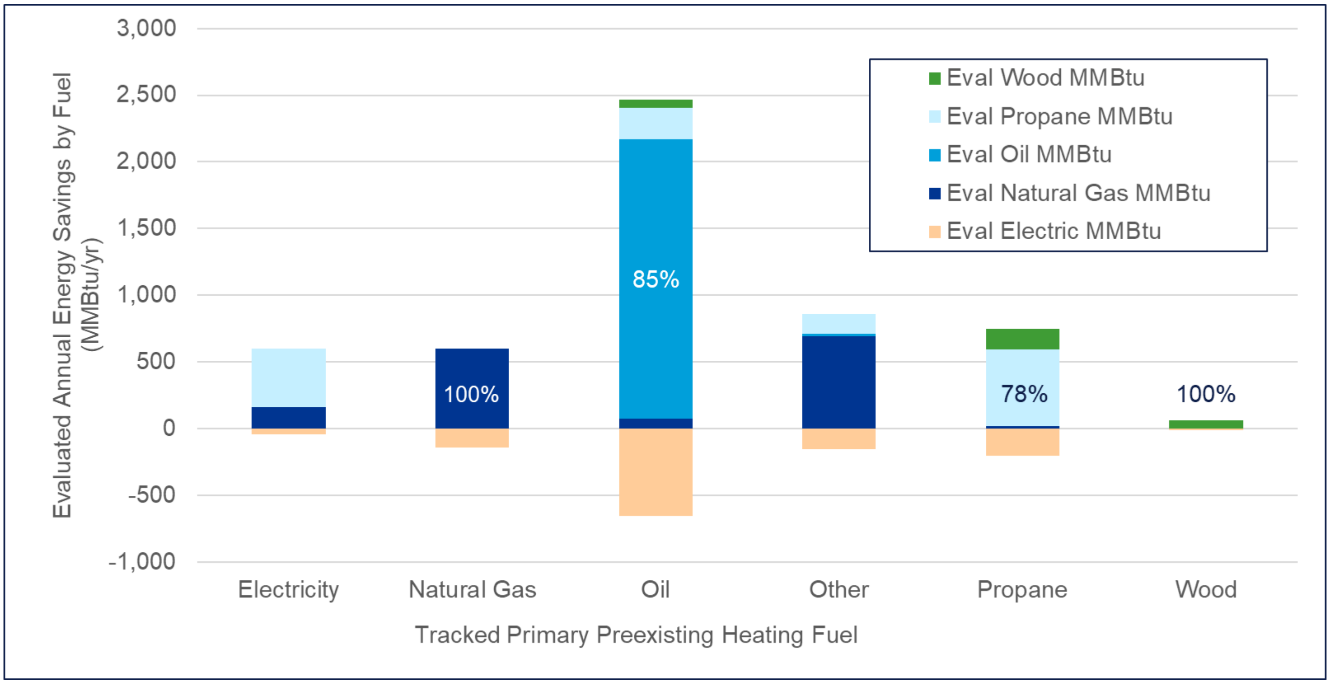


Figure B-4. Evaluated Energy Savings by Fuel vs. Tracked Primary Preexisting Heating Fuel



B.2 ASHP Results

Figure B-5. ASHP Results by Fuel after Evaluator Reclassification of Reported Savings by Tracked Fuel Type

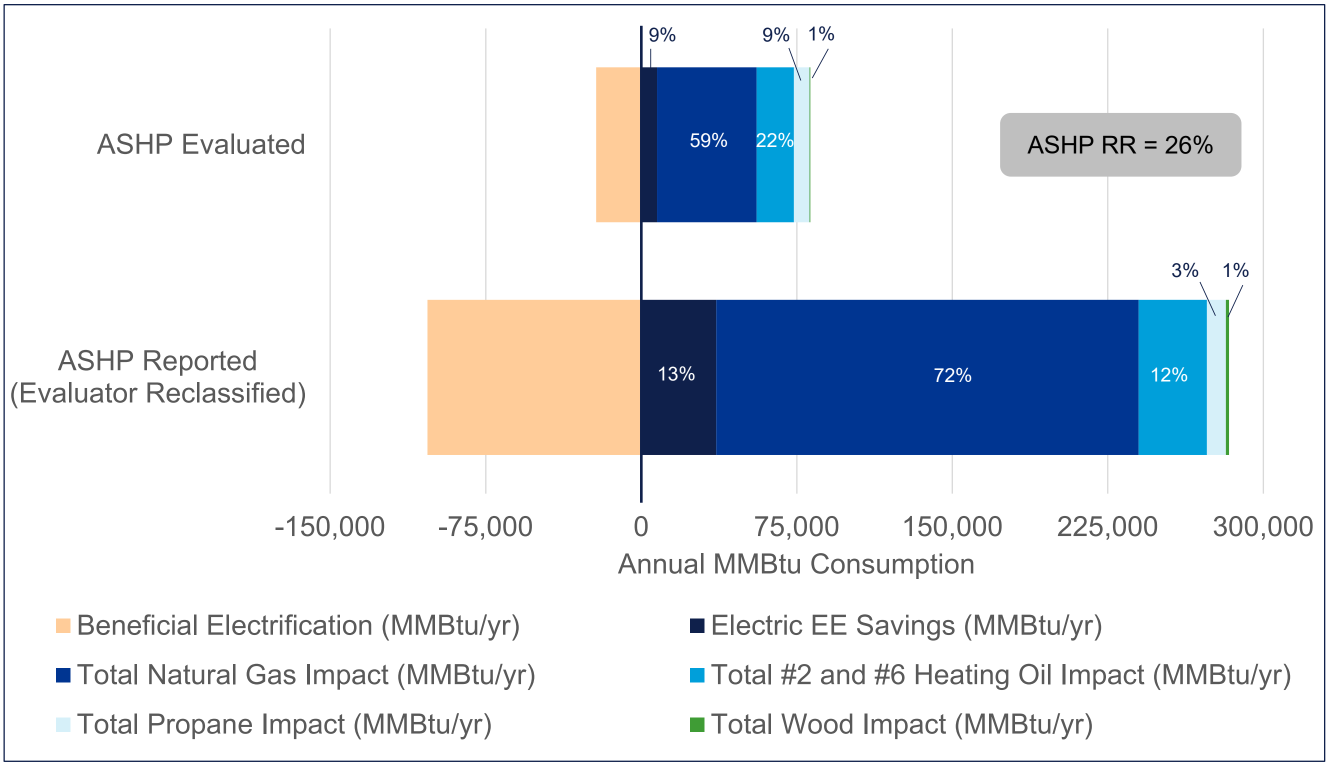


Table B-8. ASHP Results by Customer Type

Customer Type	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Multifamily	623	3	55,348	16,717	0.30	115%	35%
Single-Family Residential	3,422	83	173,025	45,388	0.26	35%	9%
Total ASHP	4,045	86	228,373	60,161	0.26	34%	9%

Figure B-6. ASHP Results by Tracked Preexisting Heating Fuel Type

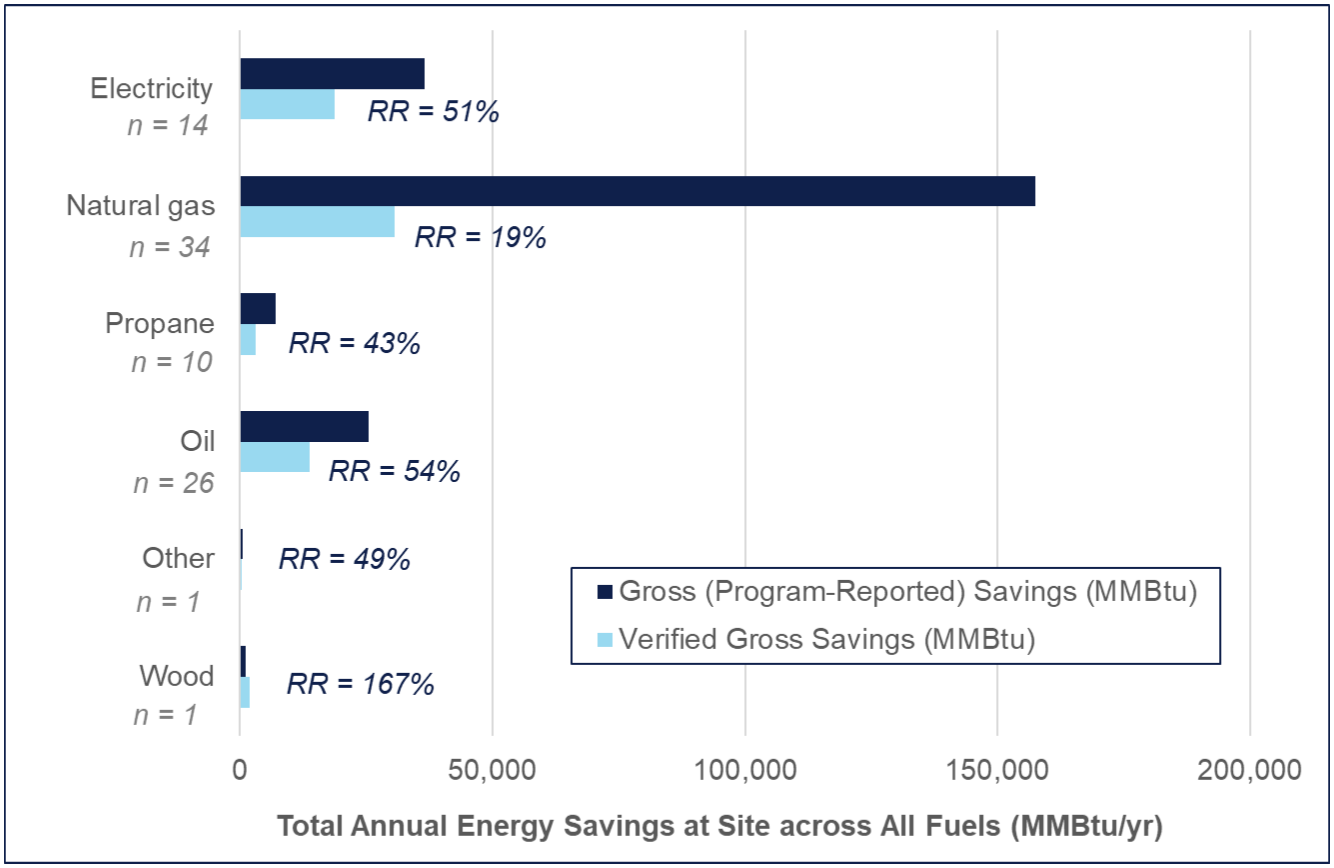
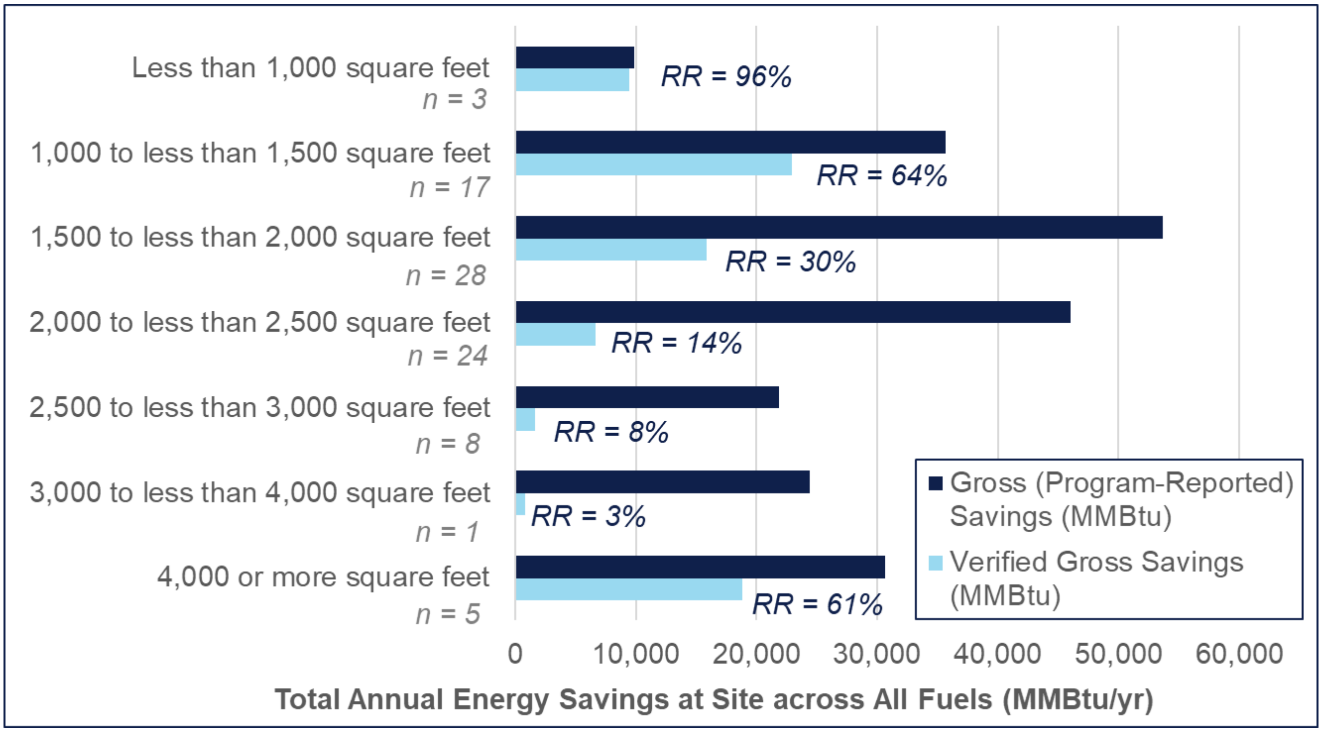


Figure B-7. ASHP Results by Tracked Square Footage Affected by the ASHP Installation



B.3 GSHP Results

Table B-9. GSHP Results by Tracked Preexisting Heating Fuel Type

Preexisting Heating Fuel	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Electricity	118	5	4,024	8,572	2.13	30%	64%
Propane	60	13	7,510	2,909	0.39	14%	6%
Oil	106	12	12,187	5,094	0.42	29%	12%
Other	160	6	17,025	7,555	0.44	20%	9%
Total GSHP	444	36	40,746	21,398	0.53	14%	7%

Table B-10. GSHP Results by Tracked Preexisting Heating System Type

Preexisting Heating System	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
Forced Air	146	17	17,135	6,870	0.40	24%	10%
Heat Pump	76	3	1,382	1,817	1.31	49%	64%
Hydronic Boiler	34	2	4,193	1,999	0.48	4%	2%
Other	202	14	21,367	13,240	0.62	31%	19%
Total GSHP	458	36	44,078	23,148	0.53	14%	7%

Table B-11. GSHP Results by Tracked Square Footage Affected by the GSHP Installation

Tracked Conditioned Area	N	n	Gross (Program-Reported) Savings (MMBtu)	Verified Gross Savings (MMBtu)	VGS Realization Rate	Relative Precision @ 90% CI	Absolute Precision @ 90% CI
1,000 to less than 1,500 square feet	24	1	1,501	692	0.46	0%	0%
1,500 to less than 2,000 square feet	51	3	4,146	625	0.15	105%	16%
2,000 to less than 2,500 square feet	77	3	5,629	1,349	0.24	83%	20%
2,500 to less than 3,000 square feet	61	7	5,084	3,077	0.61	30%	18%
3,000 to less than 4,000 square feet	117	10	11,473	4,313	0.38	26%	10%
4,000 or more square feet	137	12	16,024	12,859	0.80	26%	21%
Total GSHP	467	24	43,857	23,032	0.53	14%	7%

APPENDIX H. COVID BEHAVIOR SURVEY

On January 29, 2021, DNV (formerly ERS) finalized the web-based customer survey instrument used to determine changes in occupancy and behavior during COVID periods starting in March 2020. A copy of the COVID behavior survey is included in this appendix.

NYSERDA Heat Pump Evaluation: COVID-19 Behavior Survey

Date: 01/29/2021

Purpose

The COVID-19 pandemic has had major impacts throughout society. We are collecting data to determine how residential use behaviors have changed since the pandemic and their impacts on energy consumption and heat pump use. This survey will collect qualitative data from customers about their occupancy and conditioning behaviors before and after the pandemic began. The results of this survey will inform and potentially help explain the results of a billing analysis that will quantitatively determine the energy impacts of these behavior changes.

Throughout the survey, periods "before" and "after" COVID are discussed. ERS is considering mid-March 2020 as the transition between these two periods, based on the initial stay-at-home orders put in place by the State of New York.

NYSERDA's program staff are also interested in using this opportunity to ask customers that received quality assurance program interventions. The last section of questions is based on inputs from program staff.

Table 1: Research Objectives Mapped to Questions in This Instrument

Research Objectives	Survey Questions Address the Objectives
Determine residential behavioral changes due to COVID-19, including occupancy and conditioning levels	Q1 - Q14
Determine effects of NYSERDA's QA program interventions on heat pump use	Q15

Instrument and Data Collection Information

Table 2: Overview of Data Collection Approach

Data Collection	Description
Population Description	NYSERDA Heat Pump Evaluation Phase 1 survey participants
Population Size/Sample Frame	751
Type of Sampling	Census
Target Sample - Survey Completions	215
Instrument Type	Mixed-mode Survey
Survey/Interview Length	10-15 minutes
Description of Contact Sought	Customers of the NYSERDA Heat Pump Programs that participated in the Phase 1 survey and are aware of building use patterns

PROGRAMMER INFORMATION

Programming instructions are CAPITALIZED.

The evaluation team will input the following data from the [**NYSERDA Heat Pump Evaluation**] database(s) in order to reference the information during the interview. Throughout this instrument, pipe in fields are denoted by brackets and capital letters: [CUSTOMER ADDRESS].

Table 3: Database Information Piped into the Survey Instrument

Variable Name	Variable Description and Values
CUSTOMER NAME	Text field containing the name of the Phase 1 respondent
CUSTOMER ADDRESS	Text field containing the installation address from tracking data
SECTOR	HOME or BUSINESS Text field identifying the sector of the heat pump installation
INSTALLATION DATE	Date field containing heat pump installation date in Mmm YYY format
TECHNOLOGY	ASHP or GSHP
DELIVERED FUEL	TRUE or FALSE Binary field indicating whether a customer was part of the Phase 1 billing analysis and if they use delivered fuels

INSTRUMENT

Email Survey Invitation Letter

Subject: NYSERDA Request Regarding Your Heat Pump

Dear [NAME]:

The New York State Energy Research and Development Authority (NYSERDA) is conducting an important study to understand the use of Heat Pumps in New York State since the coronavirus outbreak began.

I am contacting you because you participated in a survey about one year ago to tell us about your heat pump installed at [ADDRESS]. We need your help now to learn about how you have used your heat pump since the coronavirus outbreak began.

We are asking for your participation in a brief 10-15 minute follow-up survey that can be completed online at your convenience. We understand your time is valuable, and we are offering a **$25 Amazon gift card** as a thank you for your participation.

To take the survey, please follow this link:
Take the Survey

Independent research firms ERS and APPRISE are conducting this study on behalf of NYSERDA. The information you provide will be kept confidential to the extent permitted by law including but not limited to the Freedom of Information Law (FOIL). The analysis will only use summary level data and will not identify individual respondents. Your participation will not affect any incentives you may qualify for in the future.

This important survey with provide NYSERDA with vital information to improve our programs. If you have any questions about this study, please contact Tracey DeSimone at tracey.desimone@nyserda.ny.gov. Thank you in advance for your participation.

Sincerely,

Dan Pidgeon

ERS Representative
(917) 210-2461
dpidgeon@ers-inc.com

NYSERDA - Independent Contractor
17 Columbia Circle | Albany, NY 12203-6399

nyserda.ny.gov
follow : friend : connect with NYSERDA
Click here to opt-out of receiving future emails for this study. [INCLUDE OPT-OUT LINK]

Phone Introduction

Hello, my name is [*caller name*] and I am calling from APPRISE on behalf of the New York State Energy Research and Development Authority, also known as NYSERDA. We are contacting you because you participated in a short survey last year regarding the heat pump(s) installed in your home/building. Thank you again.

I'm calling now because we'd like to ask you a few short questions about how you have been using your heat pump since the coronavirus pandemic began. This survey will take about 10 to 15 minutes and you'll receive a $25 Amazon gift card for participating.

Your participation in this important study will help NYSERDA improve their programs amid these challenging times. All information will be kept private to the extent permitted by law.

As state orders and case intensities continue to evolve, we are planning to contact you again in several months to continue to monitor these dramatic changes in daily livelihood. You will receive an additional $25 Amazon gift card upon participating in the second stage of the survey.

Screening

Welcome to the NYSERDA Heat Pump follow up survey. This survey will take approximately 10-15 minutes to complete and will cover questions about the use of your heat pump during the coronavirus outbreak. We are offering a $25 gift card as a thank you for your participation. NYSERDA will be using this information to get a better understanding of their energy efficiency impacts through the heat pump program and changes in energy consumption due to the coronavirus pandemic.

The information you provide will be kept confidential to the extent permitted by law including but not limited to the Freedom of Information Law (FOIL). The analysis will only use summary level data and will not identify individual respondents. Your participation will not affect any incentives you may qualify for in the future. The survey begins below:

[ALL]

S1. Do you occupy the [SECTOR] at [CUSTOMER ADDRESS] at least part of the year?

[SINGLE RESPONSE]

1. Yes, occupy the home the whole year
2. Yes, occupy the home at least part of the year
3. No, do not occupy the address at all

[IF S1=3]

S2. Could you provide the contact information for the best person to talk to about the energy use patterns and the heat pump installation at [CUSTOMER ADDRESS]?

[MULTIPLE RESPONSE]

1. Name: [OPEN RESPONSE]
2. Email: [OPEN RESPONSE]
3. Phone number: [OPEN RESPONSE]

[THANK AND TERMINATE]

[IF S1=1 OR 2]

S3. Do you own or rent the [SECTOR] at [CUSTOMER ADDRESS]?

[SINGLE RESPONSE]

1. Own
2. Rent
3. Other: [OPEN RESPONSE]

COVID Impacts on Energy Behavior

[IF S1=1 OR 2]
Q1. How many people typically occupied the [SECTOR] **before** the coronavirus (COVID-19) first affected New York State in March 2020?

[SINGLE RESPONSE]

1. [NUMERIC ENTRY BOX]
-98. Don't know

[IF S1=1 OR 2]
Q2. Has the number of people occupying the [SECTOR] changed since COVID-19 started? If yes, how many people have occupied the [SECTOR] **after** COVID?

[SINGLE RESPONSE]

1. No
2. Yes: [NUMERIC ENTRY]
-98. Don’t know

[IF S1=1 OR 2]
Q3. On average, how many hours per day was your [SECTOR] occupied **before COVID-19 shutdowns** began? Please provide estimates for a typical weekday and a typical weekend day.

[MULTIPLE RESPONSE]

1. Average hours on a typical weekday: [NUMERIC ENTRY]
2. Average hours on a typical weekend day (Saturday or Sunday): [NUMERIC ENTRY]
-96. If needed, please add any notes to explain your answer: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF S1=1 OR 2]
Q4. Based on your prior response, your [SECTOR] was occupied [WEEKDAY PERCENT TIME HOME]% of the time on an average weekday and [WEEKEND PERCENT TIME HOME]% of the time on an average weekend day **before the coronavirus outbreak began**. Have the average number of hours your [SECTOR] was occupied changed since COVID-19 shutdowns first started in March 2020?

[SINGLE RESPONSE]

1. No
2. Yes
-96. Other, please specify: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF Q4 =1]
Q5. In March through May 2020, how many hours, on average, was your [SECTOR] occupied?

[MULTIPLE RESPONSE]

1. Average hours on a typical weekday: [NUMERIC ENTRY]
2. Average hours on a typical weekend day: [NUMERIC ENTRY]
-96. If needed, please add any notes to explain your answer: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF Q4 =1]
Q6. In June through August 2020, how many hours, on average, was your [SECTOR] occupied?

[MULTIPLE RESPONSE]

1. Average hours on a typical weekday: [NUMERIC ENTRY]
2. Average hours on a typical weekend day: [NUMERIC ENTRY]
-96. If needed, please add any notes to explain your answer: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF Q4 =1]
Q7. In September through November 2020, how many hours, on average, was your [SECTOR] occupied?

[MULTIPLE RESPONSE]

1. Average hours on a typical weekday: [NUMERIC ENTRY]
2. Average hours on a typical weekend day: [NUMERIC ENTRY]
-96. If needed, please add any notes to explain your answer: [OPEN-ENDED RESPONSE]
-97. Don't know

[IF S1=1 OR 2]
Q8. We would like to learn about how the average temperature settings you have used on your thermostats may have changed since COVID-19 began in March 2020.

Since COVID-19 began, how have you changed the typical temperature setting on your thermostat during **the colder months when you want to heat your [sector]**?

Please indicate this using the table below.

[MULTIPLE RESPONSE]

	Set temperature much cooler (More than 3°F lower than before)	Set temperature somewhat cooler (1°F to 3°F lower than before)	Kept temperature settings about the same as before	Set temperature somewhat warmer (1°F to 3°F higher)	Set temperature setting much warmer (More than 3°F higher)
Occupied (Awake)	☐	☐	☐	☐	☐

Occupied (Sleeping)	☐	☐	☐	☐	☐
Unoccupied	☐	☐	☐	☐	☐
Business hours	☐	☐	☐	☐	☐
Closed hours	☐	☐	☐	☐	☐
Holiday hours	☐	☐	☐	☐	☐

[IF S1=1 OR 2]
Q9. Since COVID-19 began, how have you changed the typical temperature setting on your thermostat **during the warmer months when you want to cool your [sector]**?

[MULTIPLE RESPONSE]

	Set temperature much warmer (more than 3°F higher than before)	Set temperature somewhat warmer (1°F to 3°F higher than before)	Kept temperature settings about the same as before	Set temperature somewhat cooler (1°F to 3°F lower than before)	Set temperature much cooler (More than 3°F lower than before)
Occupied (Awake)	☐	☐	☐	☐	☐
Occupied (Sleeping)	☐	☐	☐	☐	☐
Unoccupied	☐	☐	☐	☐	☐
Business hours	☐	☐	☐	☐	☐
Closed hours	☐	☐	☐	☐	☐
Holiday hours	☐	☐	☐	☐	☐

[IF S1=1 OR 2]
Q10. Does your [SECTOR] have any of these? Select all that apply.

[MULTIPLE RESPONSE]

1. Solar PV System or Panels
2. Electric vehicles
3. Other devices that use a large amount of electricity: [OPEN-ENDED RESPONSE]
4. None of the above
-98. Don't know

[IF S1=1 OR 2 AND Q10=1]
Q11. When did you install your solar PV system?

[SINGLE RESPONSE]

1. Before heat pump installation in [INSTALLATION DATE]
2. Between [INSTALLATION DATE] and March 2020

3. After March 2020
-96. Other, please specify: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF S1=1 OR 2 AND Q10=2]
Q12. When did you purchase your electric vehicle?

[SINGLE RESPONSE]

1. Before heat pump installation in [INSTALLATION DATE]
2. Between [INSTALLATION DATE] and March 2020
3. After March 2020
-96. Other, please specify: [OPEN-ENDED RESPONSE]
-97. Don't know

[IF S1=1 OR 2]
Q13. Has your [SECTOR] undergone any significant changes since the installation of your heat pump? (Examples include: other changes to your heating/cooling systems, envelope/insulation upgrades, additions/renovations, adding a swimming pool, change in tenants in multifamily building)

[SINGLE RESPONSE]

1. No
2. Yes, please explain: [OPEN-ENDED RESPONSE]
-96. Other, please specify: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF S1=1 OR 2 AND Q13 = 1 OR -96]
Q14. When did the significant changes you explained in the previous question occur?

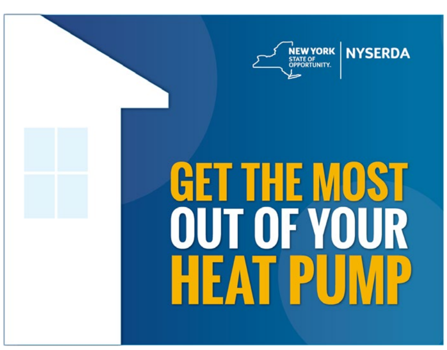
[SINGLE RESPONSE]

1. Before March 2020
2. After March 2020
3. Other: please specify [OPEN-ENDED RESPONSE]
-98. Don't know

NYSERDA Program Impact

[IF S1=1 OR 2 AND TECHNOLOGY = ASHP]
Q15. More than a year ago, NYSERDA mailed you a pamphlet explaining ways you could use your heat pump to maximize energy savings.

Do you recall receiving this pamphlet in Spring 2019?



[SINGLE RESPONSE]

1. Yes

2. No
-98. Don't know

[Q15=1]
Q16. On a scale of 1 to 5, where 1 is not helpful and 5 is very helpful, how informative did you find this pamphlet?

[SINGLE RESPONSE]

1. 1 – 5 button scale with a "Do Not Recall" option

[Q15=1]
Q17. Once you received the pamphlet, what was its impact on the operation of your heat pump? Please select any that apply.

[MULTIPLE RESPONSES]

1. No impact
2. I operate my heat pump more frequently *Randomize
3. I adjusted my central system's thermostat settings *Randomize
4. I adjusted my heat pump's settings (temperature setpoints, modes, and/or fan operation) *Randomize
5. I adjusted dampers, vanes, or doors to redistribute heat properly *Randomize
6. I clean my heat pump more frequently *Randomize

-96. Other, please specify: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF S1=1 OR 2]
Q18. On a scale of 1 to 5, where 1 is very dissatisfied and 5 is very satisfied, how would you rate your satisfaction with your heat pump?

[SINGLE RESPONSE]

1 – 5 button scale
[IF Q18 <4]

Q19. Why did you give that rating?

1. [OPEN-ENDED RESPONSE]

[IF S1=1 OR 2]

Q20. When your heat pump was installed in [INSTALLATION DATE], did your contractor provide instruction about how to operate your heat pump? If yes, please describe what type of instruction your contactor provided.

[SINGLE RESPONSE]

1. Yes: [OPEN-ENDED RESPONSE]
2. No

-96. Other, please specify: [OPEN-ENDED RESPONSE]
-98. Don't know

Fuel Supplier Data

[IF S1=1 OR 2 AND IF DELIVERED_FUEL=TRUE]
Q21. Have you changed your fuel supplier (heating oil or propane) since January 2020?

[SINGLE RESPONSE]

1. No
2. Yes

3. No longer have fuel supplier
-96. Other, please specify: [OPEN-ENDED RESPONSE]
-98. Don't know

[IF Q16=1]

Q22. As an extension of our study, we would like to analyze your energy use habits. To do this, NYSERDA and your fuel companies need consent and approval to release your energy usage data. Are you willing to release your energy data and update your consent form?

[SINGLE RESPONSE]

1. Yes, I am willing to participate
2. No, I would rather not participate

[IF Q17=1]

Q23. **<u>Billing Information Release Consent Form</u>**
By providing the account numbers for the property listed below, I hereby authorize the identified energy companies to release, to NYSERDA and/or its designated representatives, energy billing and consumption data for the property listed for up to the past 60 months. I understand that NYSERDA will use this data only for evaluation purposes related to heat pumps, that results will be reported only in the aggregate, and that the data obtained pursuant to the agreement will be treated as confidential to the extent permitted by law, including the Freedom of Information Law.

[CUSTOMER ADDRESS]

Please enter the following information from a bill from the NEW company that provides heating fuel to your [SECTOR].

[MULTIPLE RESPONSE]

1. Name of fuel provider: [OPEN-ENDED RESPONSE]
2. Fuel type: [OPEN-ENDED RESPONSE]
3. Account number: [OPEN-ENDED RESPONSE]
4. Name as it appears on account: [OPEN-ENDED RESPONSE]

Survey Closeout

[IF S1=1 OR 2]
=1 OR 2]
Q24. Please confirm your name and phone number, and provide what email address we should send your Amazon Gift Card to. You will receive your gift card next Wednesday. It will come directly from Amazon.

If you wish to decline your gift card, please leave the email address field blank.

[MULTIPLE RESPONSE]

1. Name: [OPEN-ENDED RESPONSE]
2. Phone Number: [OPEN-ENDED RESPONSE]
3. Email: [OPEN-ENDED RESPONSE]

[IF S1=1 OR 2]
Q25. Is this email the best place to reach you at for our follow-up survey in 4-6 months?

[SINGLE RESPONSE]

1. Yes
2. No, please contact: [OPEN-ENDED RESPONSE]
-96. Other, please specify: [OPEN-ENDED RESPONSE]
-97. Not applicable

-98. Don't know

Closing Text

Thank you for your participation in this important study. We will be following up with you in 4-6 months to ask about your winter habits and potential future habits. As mentioned, you will find the gift card in the inbox of the email you provided in approximately one week.

APPENDIX I. COVID IMPACTS MEMO

On December 13, 2021, DNV submitted to NYSERDA a memorandum summarizing the results of the premise-level (Phase 1) impact analysis before and during COVID periods. A copy of the memo is included in this appendix.

Memo to:
Tracey DeSimone – NYSERDA
Elizabeth Boulton - NYSERDA

From: Nelson Chiu - DNV
Date: December 13, 2021

Copied to:
Jon Maxwell – DNV
Patrick Hewlett – DNV

Prep. By: Nelson Chiu - DNV

NYSERDA Heat Pump Evaluation – COVID Billing Analysis

EXECUTIVE SUMMARY

Researchers followed up with NYSERDA Phase 1 heat pump study participants to determine any effects of COVID on residential site heating, cooling, and base load energy use. Surveys were sent to all 775 residential participants, of which 362 completed the survey and released their energy billing data. After attrition for utility energy data collection (86% success) and data cleaning 184 sites met the requirements for analysis. Analysts conducted a five-point linear regression analysis of each facility against weather for both pre-COVID and during-COVID periods (both periods were after the heat pump installation) to determine energy use and change then aggregated the results.

The analysis shows an increase in base load and heating load and a decline in the much smaller cooling energy load. The amounts are summarized in Table ES-1.

Table ES-1. Results Summary

Parameter	Change During COVID-19 Period	
	Self-Described Behavior	Measured Increase (Decrease) in Energy Use
Heating	75% no change; 0.1°F warmer setpoint on average for others	11% and 4.9 MMBtu
Cooling	81% no change; 0.2°F cooler setpoint on average for others	(12%) and (0.3) MMBtu
Base load	3.0 hours per day occupancy increase - Weekdays 1.3 hours per day occupancy increase - Weekends	5% and 1.9 MMBtu

1 EVALUATION OBJECTIVES

This evaluation study is an extension to the NYSERDA Heat Pump Impact Evaluation with a focus on the impacts of COVID-19. Specifically, the objectives of this evaluation study are to quantify the impacts of COVID-19 on residential customer's energy use and home conditioning behaviors. This memo addresses methods and results that achieve the following objectives:

- **Quantify impact of COVID-19 on residential energy usage.** Compare existing Phase 1 results (post-heat pump installation / pre-COVID) to the billing data after March 2020 (post-heat pump installation /amid-COVID).
- **Characterize changes to heating and cooling behaviors due to COVID-19.** Review results of customer survey on how heating and cooling behaviors changed to heat pump participants surveyed in Phase 1.

2 METHODOLOGY

This section describes the methods applied to collect the data and to develop the COVID billing analysis.

2.1 Customer Surveys

The DNV team conducted a Qualtrics-based mixed-mode survey from January 2021 to March 2021 of heat pump participants who responded to the customer survey in Phase 1 to collect input on how the COVID pandemic has impacted heating or cooling behaviors. The survey responses provide a more in-depth understanding of occupancy changes, space modifications, and heating and cooling setpoint changes during part of the COVID period from March 2020 to Jan 2021. Additionally, the survey collected customer authorizations to request utility and delivered fuel account information. Table 2-1 shows the distribution of surveys to heat pump participants who responded to the customer survey in Phase 1. DNV attempted to reach all 775 Phase 1 participants by either email or letter. 362 of 775 (47%) Phase 1 participants responded and completed the COVID Behavior Survey.

Table 2-1: Survey Distribution and Attrition Summary

Analysis Requirement	Participants Retained	Participants Removed	Attrition Reason
Total Population	**775**	**-**	**N/A**
Email received	763	12	0 – Email address not valid
Attempted Survey	366	397	1 – Did not respond to survey
Completed the survey	362	4	2 – Did not complete survey
Total	**362**	**413**	

2.2 Data Requests

The DNV team compiled the utility data authorizations for data requests. The team prepared batch data requests for entering into the Electronic Data Interchange (EDI) for electric and gas billing data after March 2020. When data was not available through EDI, the team prepared individual data requests for each of the investor-owned utilities (IOUs). The evaluation team received data for 326 of the 381 (86%) of meters requested. Table 2-2 shows the summary of received data from Con Edison, Orange & Rockland, Central Hudson, National Grid, National Fuel, NYSEG, and RG&E.

Table 2-2. Utility Data Collection

Utility Name	Meters with no data received	Meters with data received	Total Meters	Percent of Meters received
Central Hudson - ELECTRIC	6	82	88	93%
Central Hudson - GAS	0	2	2	100%
ConEdison - ELECTRIC	6	47	53	89%
ConEdison - GAS	1	14	15	93%
National Fuel - GAS	0	8	8	100%
National Grid - GAS	25	1	26	4%
National Grid (Nimo) - ELECTRIC	8	68	76	89%
NYSEG - ELECTRIC	4	69	73	95%
NYSEG - GAS	2	9	11	82%
O&R - ELECTRIC	2	3	5	60%
RGE - ELECTRIC	1	16	17	94%

RGE - GAS	0	7	7	100%
Total	**55**	**326**	**381**	**86%**

The DNV team, with support from APPRISE, attempted to collect fuel delivery records for all customers who provided supplier or account information. Table 2-3 shows the breakdown of fuel supplier accounts received.

Table 2-3. Fuel Supplier Data Collection

Status	Total Meters	Percent of Meters
Data received	43	86%
No data received	16	14%
Customer moved	1	2%
Supplier did not provide data	1	2%
Total	**61**	**100%**

2.3 COVID Billing Analysis

The DNV analysts standardized the data format for utility billing data and fuel supplier billing data, cleaned periodic energy use readings and associated each reading to relevant weather. See Attachment A1 for further details on the data cleaning process.

After cleaning the billing data, the team attempted a billing regression analysis for each meter for the COVID period (after March 2020). The team used a variable base degree day linear regression model to estimate energy usage during COVID. Since, the team calculated optimal base degree-day temperatures for each meter from the Phase 1 analysis, these same base temperatures were used for the regressions models during COVID. For sites with electric heating and cooling, the team fit a 5-parameter change point model. For fossil fuels and sites with electric heating or cooling but not both, 3-point models were used. See Attachment A2 for further details on the change point models.

After the establishing the relationship between energy use and recent outside air temperature during COVID, the annual energy use was weather normalized by applying the COVID model to typical meteorological weather data for the last ten years. The team then rolled up annual energy use per meter into annual energy use on a site level.

2.3.1 Analysis Filtering Scenarios

From the Phase 1 Analysis and in consultation with West Hill Energy and NYSERDA, the team developed three analysis filtering scenarios (Mild, Moderate, and Strict) to present a range of evaluated results. Each scenario incorporates increasing levels of strictness in regard to data cleanliness, statistical significance, and weather dependency. For the COVID Billing Analysis, the DNV team uses the same three filtering scenarios to present a range of results. The filtering scenarios are shown in Table 2-4 and are different for electric and fossil fuel meters.

Table 2-4. Tiered Filtering Criteria

Fuel Type	Period	Scenario	Days of Data	Bill Reads	R^2	Statistical test
Electric	Pre-COVID and amid-COVID	Strict	>270 days	<50% estimated	>0.6	t-value >2 or p-value < 0.05
		Moderate	>270 days	<50% estimated	>0.2	Any
		Mild	>270 days	Any	Any	Any
Fossil Fuels	Pre-COVID and amid- COVID	Strict	>180 days	<50% estimated	>0.6	t-value >2 or p-value < 0.05
		Moderate	>180 days	<50% estimated	>0.6	Any
		Mild	>180 days	Any	Any	Any

1. **Bill read requirements are not applicable to delivered fuels**
2. **Statistical tests requirements are applied on the HDD and CDD slopes**
3. **Statistical tests requirements are not applicable to fossil fuel CDD regressions**

2.3.2 Billing Analysis Attrition

From Phase 1, there were 305 sites that met the Mild, Moderate or Strict scenarios listed in Table 2-4. DNV reviewed sites on billing data requirements to include into the COVID Billing Analysis. 184 of 305 sites from Phase 1, met the billing data requirements for inclusion into the COVID Billing representing an attrition rate of 40%. The attrition summary and billing data requirements are listed in Table 2-5.

For the 184 sites included in the COVID Billing Analysis, all 184 sites are included in the mild scenario. 119 sites are included in the moderate scenario and 68 sites are included in the strict scenario. Similar to Phase 1, the moderate filtering criteria removes sites with little to no weather dependency that are kept in the mild scenario and maintain higher sample sizes than the strict scenario. The evaluation team recommends using the moderate filtering criteria for consistency with Phase 1 findings when comparing the COVID impact on energy usage.

Table 2-5: Billing Analysis Attrition Summary

Analysis Requirement	Sites Retained	Sites Removed	Attrition Reason
Total population	**305**	**-**	**Sites from Phase 1 with Mild, Moderate or Strict Scenarios**
Received electric data	296	9	1 – No electric data
Expected fossil fuel data and received it	252	44	2 – Expected fossil fuel data and none received
Sufficient electric data (>= 270 days)	240	12	3 – Insufficient electric data (<270 days of data)
Sufficient fossil fuel data (>= 180 days) where expected	232	8	4 – Insufficient fossil fuel data (<180 days of data)
Participant lives in home or stays part of the year	216	16	5 – Participant moved out of home
No Solar/PV installed on site	184	32	6 – Solar/PV installed on site
Total	**184**	**121**	

2.3.3 Aggregate Analysis

The final site analysis results were expanded to the sample frame using ratio estimation and a set of sample weights based on the sample design by electric only sites and electric and fossil fuel sites to produce of during COVID to pre-COVID ratios on energy usage. Each weight is specific to an individual stratum and calculated as the number of units in the sample frame (N) for the stratum divided by the number of completed units in the sample (n) for the stratum. The interpretation of the weight is that each completed sample unit represents N/n units in the sample frame.

Notation: The following terms are used in calculating the ratio of energy usage between pre-COVID and during COVID periods:

T_j = Calculated energy usage pre-COVID for measure j

V_j = Calculated energy usage amid-COVID for measure j

W_j = Weighting factor for measure j used to expand the sample to the population

S = Number of measures in the sample

The usage during COVID to usage pre-COVID ratios are calculated directly:

$$\frac{Amid - COVID\ Usage}{Pre - COVID\ Usage}\ Ratio = \frac{\sum_{j=1}^{S} V_j w_j}{\sum_{j=1}^{S} T_j w_j}$$

Relative precision was calculated using the procedures described in Chapter 13 of the California Evaluation Framework[1].

3 RESULTS

The sections below present the results of the survey and COVID billing analysis on how energy usage and heating/cooling behavior changed during COVID.

3.1 COVID Behavior Changes

In the survey, DNV analysts asked participants how many hours per day they were occupying their homes on weekdays and weekends pre-COVID (prior to March 2020) and during COVID periods (from March 2020 to November 2020). Prior to March 2020, participants occupied their homes for more hours during weekends (20 hours per day) than weekdays (18 hours per day). Participant behavior around occupancy during the COVID period became much more similar across weekdays and weekends with participants occupying their homes for about 21 hours a day. During the COVID period, participants were occupying their homes for an additional 3 hours per day over weekdays and 1.3 hours per day over weekends. DNV analysts found that the 60% of participants were occupying their homes for all 24 hours of the day during COVID, whereas this value was around closer to 40% prior to March 2020. See Figure 3-1 and Figure 3-2 for distribution of weekday and weekend occupancies.

[1] http://www.calmac.org/publications/California_Evaluation_Framework_June_2004.pdf

Figure 3-1. Distribution of Weekday Occupancy Hours (n=358)

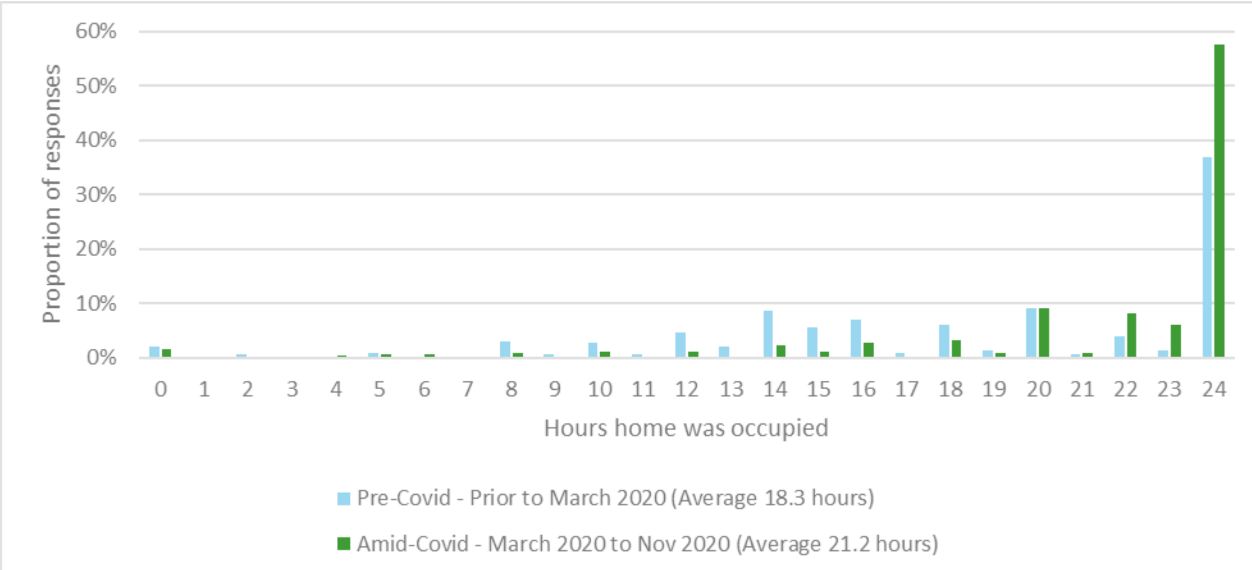
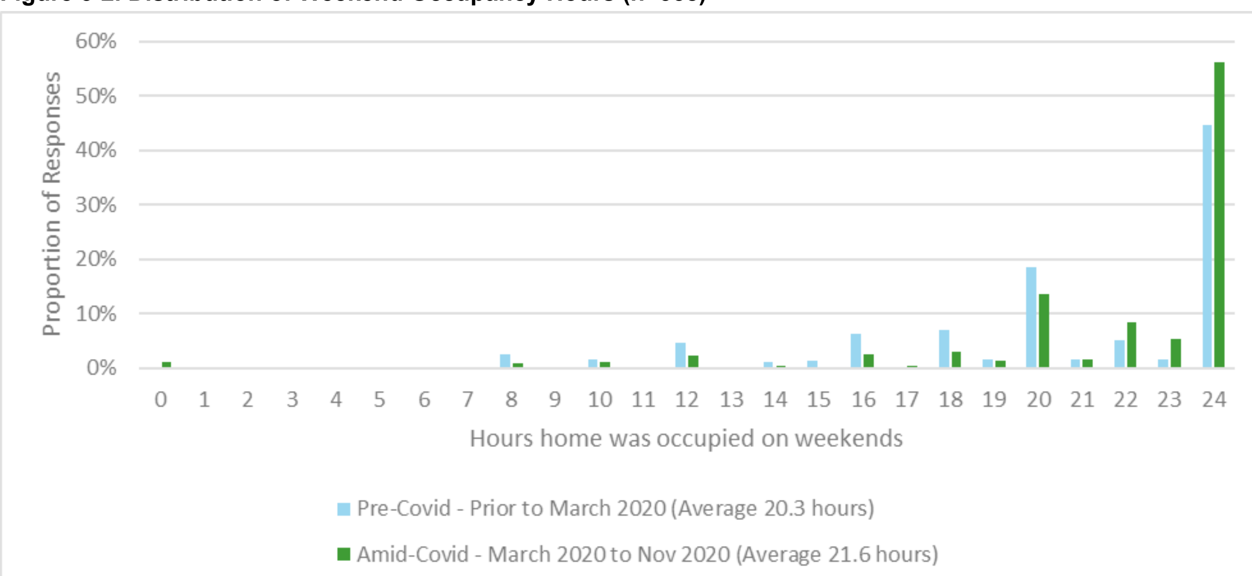


Figure 3-2. Distribution of Weekend Occupancy Hours (n=358)



In the survey, DNV analysts also asked participants on what changes (if any) did participants make to their temperature settings during the heating and cooling seasons. During the heating seasons, we saw that a majority (75%) of participants kept temperature settings about the same as the pre-COVID period. DNV analysts also probed further to identify differences in temperatures during COVID between awake, sleeping and unoccupied hours. For hours when participants were awake, a statistically significant portion (20%) of participants indicated setting the temperature somewhat warmer (1°F to 3°F higher than before) as compared to sleeping and unoccupied hours. During the cooling season, a majority (81%) of participants kept their temperatures the same as the pre-COVID period.

DNV analysts assigned a degree change based on each response as shown in Table 3-1 and Table 3-2 to estimate the average temperature setting change for participants who did adjust their temperatures. During the heating season, participants who did adjust their temperature setting on average set their temperature 0.1°F warmer. During the cooling season participants who did adjust their temperature setting set their temperature 0.2°F cooler. See Table 3-1 and Table 3-2 for further details on the response distribution.

Table 3-1. Heating Season changes to temperature settings (n=356)

Temperature Setting	Assigned Degree Change	Proportion – Occupied Awake	Proportion – Occupied Sleeping	Proportion - Unoccupied	Average Proportion
Kept temperature settings about the same as before	0°F	69%	77%	78%	75%
Set temperature somewhat warmer (1°F to 3°F higher than before	+2°F	20%[1]	7%	5%	11%
Set temperature much warmer (more than 3°F higher than before)	+5°F	6%	3%	2%	4%
Set temperature somewhat cooler (1°F to 3°F lower than before)	-2°F	3%	7%	7%	6%
Set temperature much cooler (more than 3°F lower than before)	-5°F	2%	6%	8%	5%

1. DNV found a statistically significant difference (p-value <= 0.05) in the distribution of responses between temperature settings during occupied awake hours as compared to occupied sleeping hours or unoccupied hours

Table 3-2. Cooling Season changes to temperature settings (n=356)

Temperature Setting	Assigned Degree Change	Proportion – Occupied Awake	Proportion – Occupied Sleeping	Proportion - Unoccupied	Average Proportion
Kept temperature settings about the same as before	0°F	77%	83%	83%	81%
Set temperature somewhat warmer (1°F to 3°F higher than before	+2°F	3%	3%	5%	4%
Set temperature much warmer (more than 3°F higher than before)	+5°F	3%	3%	7%	4%
Set temperature somewhat cooler (1°F to 3°F lower than before)	-2°F	13%	8%	4%	8%
Set temperature much cooler (more than 3°F lower than before)	-5°F	4%	3%	2%	3%

3.2 COVID Energy Impact

For the COVID Billing Analysis, a range of results are presented representing the three filtering scenarios (Mild, Moderate and Strict) described in Table 2-4 and segmented by electric only sites as well as electric & fossil fuel sites. The energy usage calculated during the COVID period beginning March 2020 was compared to energy usage calculated during the pre-COVID period from Phase 1. Note that the pre-COVID period refers to the time period after the installation of the heat pump and before March 2020. The total usage during COVID increased by 6.5MMBTU or 8% across all sites compared to the pre-COVID period. Table 3-3 shows the total energy usage values before and during COVID and disaggregates the impact on energy usage by electric only and electric & fossil fuel sites. Tables 3-4 through 3-6, show the base load, cooling load and heating load impacts of COVID.

In Tables 3-3 through Table 3-6, the larger bolded font numbers indicate the calculated values with the recommended moderate filtering criteria. The smaller fonts below show the calculated values for the mild and strict scenarios to illustrate a range of results. Note that the relative precisions presented are not a range. The values represent the relative precision of percent change in usage for each of the three filtering scenarios. For example, in Table 3-3 for All Sites – change in energy usage for moderate scenario is 8% +/- 5%, and the change in energy usage for the mild and strict scenarios are 5% +/- 10% and -2% +/- 4%. In this study, the values of the moderate scenario may not lie within the range of values of the mild and strict scenarios. This is expected as the mild scenario includes sites with little to no weather dependency which will inflate base load values and not be representative of cooling or heating load values as compared to the moderate scenario. On the other hand, the strict scenario applies more stringent criteria requiring statistically significant weather dependency which results in much lower sample size (68 sites) compared to the moderate scenario (119 sites) and increases the variability of the calculated values as well.

Table 3-3. Impact of COVID on Total Energy Usage

Site Type	Count	Pre-COVID Usage (MMBTU)	Amid-COVID Usage (MMBTU)	Difference in Usage (MMBTU)	Percent Change in Usage	Relative Precision @ 90% CI
Electric & Fossil Fuel	**20** 3 to 47	**133.0** 113.3 to 180.6	**141.5** 109.4 to 192.5	**8.5** -3.9 to 12	**6%** -3% to 7%	**5%** 1% to 12%
Electric Only	**99** 65 to 137	**37.1** 35.6 to 39.5	**41.9** 36.3 to 42.2	**4.8** 0.7 to 2.7	**13%** 2% to 7%	**12%** 4% to 7%
All Sites	**119** 68 to 184	**81.5** 72.5 to 83.9	**88.0** 76.1 to 82.6	**6.5** -1.3 to 3.6	**8%** -2% to 5%	**5%** 4% to 10%

1. The variation in the range of results is due to the different analysis techniques applied to each site depending on the filtering criteria, as discussed in Section 2.3.1.

The main drivers for the increased energy usage across sites were increases in base load (5% or 1.9MMBTU) and heating load (11% or 4.9MMBTU). The cooling load across sites during COVID decreased by 12% or 0.3 MMBTU. The base load increase makes sense with participants staying at home for 3 hours more per day during weekdays and 1 hour more during weekends. The increased occupancy hours correspond to more lighting and plug loads which contribute to the increased base load. The heating load accounts for about 75% of the increased energy usage during the COVID period. This also makes sense with participants with the increase occupancy hours and understanding that while participants are awake during the heating season they 20% did set their temperature setting somewhat warmer. The decrease in cooling load during the COVID period is unexpected as the DNV team expects higher occupancy hours and no changes in temperature setting to increase cooling loads. Note that the magnitude of the cooling load (2.3 MMBTU pre-COVID and 2.0 MMBTU during COVID) is small, and accounts for 2% to 3% of the total energy usage. Thus, the decrease in cooling load (0.3 MMBTU) is an even smaller fraction of the total energy usage cooling load which may be difficult to accurately detect through monthly billing analysis. See Table 3-4, Table 3-5 and Table 3-6, for the breakdown of base load, cooling load and heating load impacts.

Table 3-4. Impact of COVID on Base Load

Site Type	Count	Pre-COVID Usage (MMBTU)	Amid-COVID Usage (MMBTU)	Difference in Usage (MMBTU)	Percent Change in Usage	Relative Precision @ 90% CI
Electric & Fossil Fuel	**20** 3 to 47	**52.6** 35.2 to 50.3	**52.1** 38.4 to 61.9	**-0.5** 3.2 to 11.6	**-1%** 9% to 23%	**6%** 6% to 24%
Electric Only	**99** 65 to 137	**20.3** 19.5 to 24.9	**24.1** 20.0 to 27.6	**3.8** 0.5 to 2.7	**19%** 3% to 9%	**13%** 5% to 10%
All Sites	**119** 68 to 184	**35.2** 23.5 to 40.2	**37.1** 24.7 to 48.2	**1.9** 1.2 to 8.1	**5%** 5% to 20%	**8%** 9% to 18%

1. The variation in the range of results is due to the different analysis techniques applied to each site depending on the filtering criteria, as discussed in Section 2.3.1.

Table 3-5. Impact of COVID on Cooling Load

Site Type	Count	Pre-COVID Usage (MMBTU)	Amid-COVID Usage (MMBTU)	Difference in Usage (MMBTU)	Percent Change in Usage	Relative Precision @ 90% CI
Electric & Fossil Fuel	**20** 3 to 47	**3.4** 1.9 to 3.2	**2.9** 1.5 to 2.0	**-0.4** -1.2 to -0.4	**-13%** -37% to -23%	**26%** 15% to 25%
Electric Only	**99** 65 to 137	**1.3** 1.5 to 1.8	**1.2** 1.3 to 1.5	**-0.1** -0.3 to -0.2	**-10%** -18% to -15%	**13%** 14% to 21%
All Sites	**119** 68 to 184	**2.3** 1.8 to 2.2	**2.0** 1.4 to 1.6	**-0.3** -0.5 to -0.4	**-12%** -20% to -25%	**18%** 16% to 22%

1. The variation in the range of results is due to the different analysis techniques applied to each site depending on the filtering criteria, as discussed in Section 2.3.1.

Table 3-6. Impact of COVID on Heating Load

Site Type	Count	Pre-COVID Usage (MMBTU)	Amid-COVID Usage (MMBTU)	Difference in Usage (MMBTU)	Percent Change in Usage	Relative Precision @ 90% CI
Electric & Fossil Fuel	**20** 3 to 47	**77.1** 61.1 to 142.2	**86.5** 46.0 to 152.1	**9.4** -15.1 to 9.9	**12%** -25% to 7%	**10%** 1% to 51%
Electric Only	**99** 65 to 137	**15.4** 13.0 to 14.3	**16.6** 13.3 to 14.8	**1.1** 0.3 to 0.5	**7%** 2% to 3%	**10%** 5% to 5%
All Sites	**119** 68 to 184	**44.0** 42.0 to 46.8	**48.9** 33.0 to 49.7	**4.9** -9.0 to 2.9	**11%** -21% to 6%	**8%** 1% to 43%

1. The variation in the range of results is due to the different analysis techniques applied to each site depending on the filtering criteria, as discussed in Section 2.3.1.

3.3 Post Stratification

DNV analysts used survey responses to stratify the COVID billing analysis results to gain a clearer understanding of participant behavior COVID to impacts in their usage. DNV analysts first looked at the impact of increased occupancy on energy usage. DNV analysts considered respondents who increased their occupancy hours by more than 3 hours during the COVID period relative to hone in on participants with the largest increases. Participants who indicated increased occupancy by more than 3 hours showed increases in total usage of 3.7 MMBTU which represents a 6% increase from the pre-COVID period. This increase in total usage is largely comprised of an increase in the base load accounting for 3.5 MMBTU or 95% of the increase with the remaining increase coming from the heating load as well 0.5 MMBTU or 13% of the increase. The cooling load for the participants with increased occupancy hours decreased by 0.4 MMBTU. This results suggests that an increase in occupancy hours is mainly driving increases in base load usage and heating load to a lesser degree. See Table 3-7 for more details.

Table 3-7. Increased Occupancy Impact on Energy usage

Survey Response	Load	Count	Pre-COVID Usage (MMBTU)	Amid-COVID Usage (MMBTU)	Difference in Usage (MMBTU)	Percent Change in Usage
Increased occupancy (> 3 hours)	Total Usage	**33** 19 to 53	**60.5** 54.7 to 62.6	**64.2** 56.3 to 68.3	**3.7** 1.6 to 5.7	**6%** 3% to 9%
	Base Load	**33** 19 to 53	**32.9** 33.3 to 33.7	**36.4** 35.6 to 41.8	**3.5** 2.3 to 8.1	**11%** 7% to 24%
	Cooling Load	**33** 19 to 53	**2.2** 1.8 to 2.3	**1.8** 1.6 to 2.1	**-0.4** -0.1 to -0.2	**-16%** -10% to -6%
	Heating Load	**33** 19 to 53	**25.5** 19.1 to 27.1	**26** 18.6 to 24.8	**0.5** -0.6 to -2.2	**2%** -3% to -8%

DNV analysts then stratified COVID energy usage impacts based on participants who indicated setting their temperature warmer during the heating months. The stratified results show that participants who increased their temperature set points during the heating season had total usage increase by 4.6 MMBTU or 8% from the pre-COVID period and is largely comprised of an increase in heating load (3.6 MMBTU or 78% of the increase) followed by an increase in base load (1.3 MMBTU or 28% of the increase). This result combined with the result on the increased occupancy impact suggests that heating load increases are largely be driven by participants increasing their temperature set points during COVID and that base load increases are largely driven by an increase in participant occupancy hours. See Table 3-8 for more details.

Table 3-8. Warmer Temperature Setpoint during Heating Season Impact on Energy Usage

Survey Response	Load	Count	Pre-COVID Usage (MMBTU)	Amid-COVID Usage (MMBTU)	Difference in Usage (MMBTU)	Percent Change in Usage
Increased heating setpoint during heating season	Total Usage	**25** 16 to 34	**56.9** 48.2 to 60.6	**61.5** 51.6 to 64.7	**4.6** 3.4 to 4.2	**8%** 7% to 7%
	Base Load	**25** 16 to 34	**30.6** 28.8 to 31.7	**31.9** 32.6 to 35.0	**1.3** 3.3 to 3.8	**4%** 11% to 13%
	Cooling Load	**25** 16 to 34	**1.4** 0.8 to 1.5	**1.2** 0.5 to 1.1	**-0.2** -0.3 to -0.4	**-14%** -33% to -26%
	Heating Load	**25** 16 to 34	**24.8** 18.6 to 27.4	**28.4** 18.4 to 28.6	**3.6** -0.2 to 1.2	**14%** -1% to 4%

4 FINDINGS

Based on the results presented in Section 3, the evaluation team has developed findings regarding energy usage and behavioral impacts among the participants during COVID-19.

- Total energy usage increased by 6.5 MMBTU or 8% between the COVID period (post-March 2020) and pre-COVID periods (pre-March 2020). The disaggregated energy usage shows that the increase in total usage comes from increases in heating (4.9 MMBTU or 12% increase in heating load) and base load (1.9 MMBTU or 5% increase in base load). The cooling load oddly decreased during the COVID period (-0.3 MMBTU or 12% decrease in cooling load). As the change in cooling load for less than 1% the total energy usage, monthly billing analysis may not be sensitive enough to detect these smaller changes in cooling load. The base load increase is driven by participants staying indoors more whereas the heating load is driven by participants increasing their temperature set point during the heating season.
- Participants indicated similar occupancy behavior across weekdays and weekends during the COVID period, spending more than 21 hours per day in their homes. This represents an increase of 3 hours per day for weekdays and 1.3 hours per day over weekends indoors as compared to the pre-COVID period. This behavioral change of staying indoors more increases the amount of occupancy hours for a home and primarily leads to driving up base load usage in terms of increased plug-in appliance and lighting loads. The heating load also increased from the higher occupancy hours, but the heating load increase is
- More than 75% of participants indicated they had no change in the temperature setting during the heating or cooling seasons. For those who did change temperature settings, there was an average increase of 0.1°F (warmer) in temperature setpoint in the heating season and an average decrease of 0.2°F (cooler) in temperature set point during the cooling season. Participants who increased their heating set point saw a direct correlation in an increase in their heating load (3.6 MMBTU or 14% increase in heating load).

ATTACHMENT A: DETAILED CLEANING AND ANALYSIS METHODOLOGY

A1. Data Cleaning

In billing analysis, data cleaning and preparation includes the following processes:

1. Converting energy use data from utility companies and unregulated fuel providers across New York into a standardized form that can be associated with available weather data for analysis and compiling it with participant and survey data.
2. Excluding bad data.
3. Compiling weather data and associating it with the billing data.

A1.1. Acquire, Convert, and Compile Billing Data

NYSERDA provided DNV with investor-owned utility (IOU) company electricity and natural gas data from March 2020 to April 2021. NYSERDA drew some of the preliminary participant IOU billing data from the Electronic Data Interchange (EDI) and remaining accounts without data were requested from the IOU directly. The evaluators secured fuel data by going directly to the fuel supplier after securing releases from customers in the survey. DNV took the following steps to standardize the data:

1. Convert received raw column headers into standardized columns:
   - site_id = identifier for the site from NYSERDA tracking data
   - service_type = (gas, electric, oil, propane, or coal)
   - data_source = (utility_name or EDI)
   - billing_start_date = start of billing period
   - billing_end_date = end of billing period
   - read_type = (estimated or actual)
   - reading_value = numerical value
   - units = (therms, gallons, kWh, etc.)

   For utilities (i.e., fuel suppliers, Central Hudson, National Fuel) that only provided delivery dates, billing start dates were based on the prior bill's delivery date.
2. Anonymize utility account numbers and service_type (e.g., gas, electric, oil, propane) pairings by mapping an anonymized key (e.g. edi_key)
   - edi_key = anonymized key to represent a unique utility account number and service type (i.e., gas, electric, oil, propane)
3. Consolidate billing data from utilities
   - Append data from each utility as new rows
4. Convert all fossil fuel readings (e.g. gas, oil, propane) into MMBTU

The team associated survey and tracking data (necessary for later analysis) with each participant before anonymizing it.

A1.2. Cleaning Billing Data

Once compiled in a standard structure, the team developed logic to clean the data. Screening criteria were to delete individual period consumption records with:

- No start date
- An error response from EDI
- Key entry errors detected with range checks, such as impossible end dates in the future, second instance of duplicates, improbably high use (values greater than 3 standard deviations from the mean were individually inspected)
- Drop data with overlapping periods and keep first instance
- For bills with duplicate data from EDI and the utility, keep data from the utility
- Estimated read status, after adding the estimated use to the next month's use. This was a routine step for IOUs with standard bimonthly reading and monthly billing.

Once individual reading data was cleaned, the team reviewed whole-home energy use patterns. Analysts excluded sites with insufficient data to perform a regression.

Total attrition rates by category are summarized in Section 2.3.2.

A1.3. Compile with Weather Data

DNV separately compiled hourly dry bulb temperatures from New York weather stations and processed each into daily average temperatures, heating degree days (HDD). Multiple sets of HDD were generated with different base temperatures, also known as balance point temperatures, as described in Section A2, below.

Each site then was associated with the nearest weather station. Consumption period data were combined and normalized with the daily weather data based on the meter read dates. The metered use and the degree days were divided by the number of days in the billing period to calculate the usage per day and the HDD per day. For each day in each billing period, a data record was created with the use per day and HDD per day.

A1.4. Compile with Tax Parcel Data

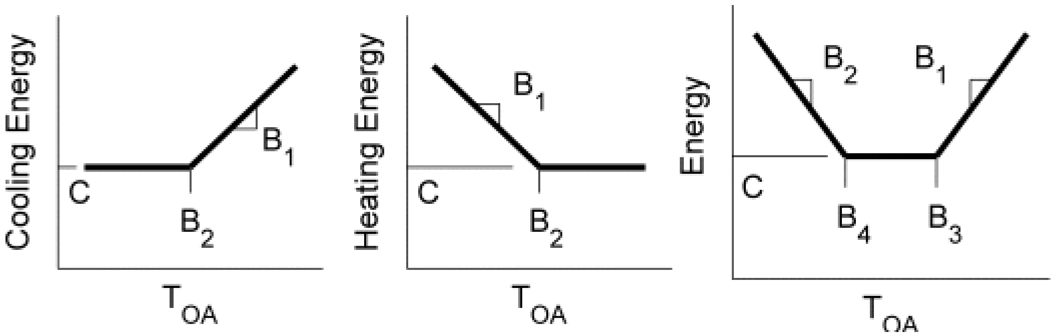
DNV acquired and consolidated tax parcel data for all counties in New York State through the web portal hosted by the New York State GIS Program Office Lands and Boundaries Unit. This dataset is associated to each site using a merge on address and provides valuable metadata on living square footage, building type and the year in which the building was built.

A2. Billing Regressions and Grid Impacts

The team attempted a site-specific analysis on all billing data available. Iterations of regressions were performed with use per day as the dependent variable and either HDD per day, CDD per day, or both as the independent variables. The base temperatures of the HDD and CDD from the Phase 1 analysis (post-heat pump and prior to March 2020) for each site were used to provide the best fitting model (CDD only , HDD only, CDD and HDD, or baseload only [non-weather dependent])for the COVID period. Figure A-1 illustrates these different "change point linear regression models." When referring to testing different base temperatures, this means finding the best curve fit by varying B_2 in the two curves at left or similarly, B_4 and B_3 in the curve at right.

Linear curves are used because both conduction and convection heat loss vary proportionally with inside-outside temperature difference. They also are simpler.

Figure A-1. Linear Change Point Regression Models[2]



Once the relationship between the site's energy use and outside temperature was established using actual weather data, these regressions were then used to calculate the normal long-term annual use by using recent 10-year average weather data.

Electric and fossil fuel billing savings were calculated based on the based on the filtering criteria discussed in Section 2.3.1.

The following equations calculate the normal modeled energy consumption for a given fuel and given case.

$$E_{case} = \sum_{i=1}^{365} C_{case} \times CDD_i + H_{case} \times HDD_i + B_{case}$$

$$EH_{case} = \sum_{i=1}^{365} H_{case} \times HDD_i$$

$$EC_{case} = \sum_{i=1}^{365} C_{case} \times CDD_i$$

where:

E_{case} =	Annual energy of given case, pre or post and fuel type (kWh or MMBtu)
EH_{case} =	Annual heating energy of given case, pre or post and fuel type (kWh or MMBtu)
EC_{case} =	Annual cooling of given case, pre or post and fuel type (kWh or MMBtu)
HDD_i =	Daily heating degree days of typical year weather for day *i*
CDD_i =	Daily cooling degree days of typical year weather for day *i*
C_{case} =	Cooling degree day constant for given case, pre or post and fuel type
H_{case} =	Heating degree day constant for given case, pre or post and fuel type
B_{case} =	Non weather dependent constant for given case, pre or post and fuel type

[2] Mitchell T. Paulus, David E. Claridge, Charles Culp, "Algorithm for automating the selection of a temperature dependent change point model," Energy and Buildings, Volume 87, 2015, Pages 95-104,
ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2014.11.033.

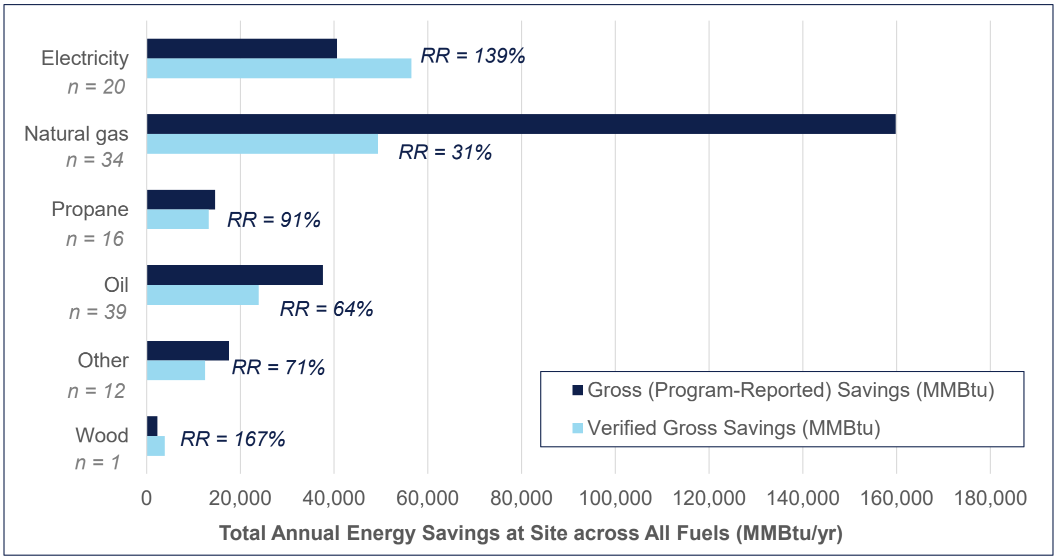
APPENDIX J. PHASE 2 ADDITIONAL RESULTS

This appendix supplements the report body with Phase 2 M&V results among various segments of interest.

Overall Results

The following figures illustrate trends in combined (ASHP and GSHP) results by key variables of interest.

Figure J-1. Combined (ASHP and GSHP) results by tracked preexisting heating fuel



Figured J-2. Combined (ASHP and GSHP) results by electric utility

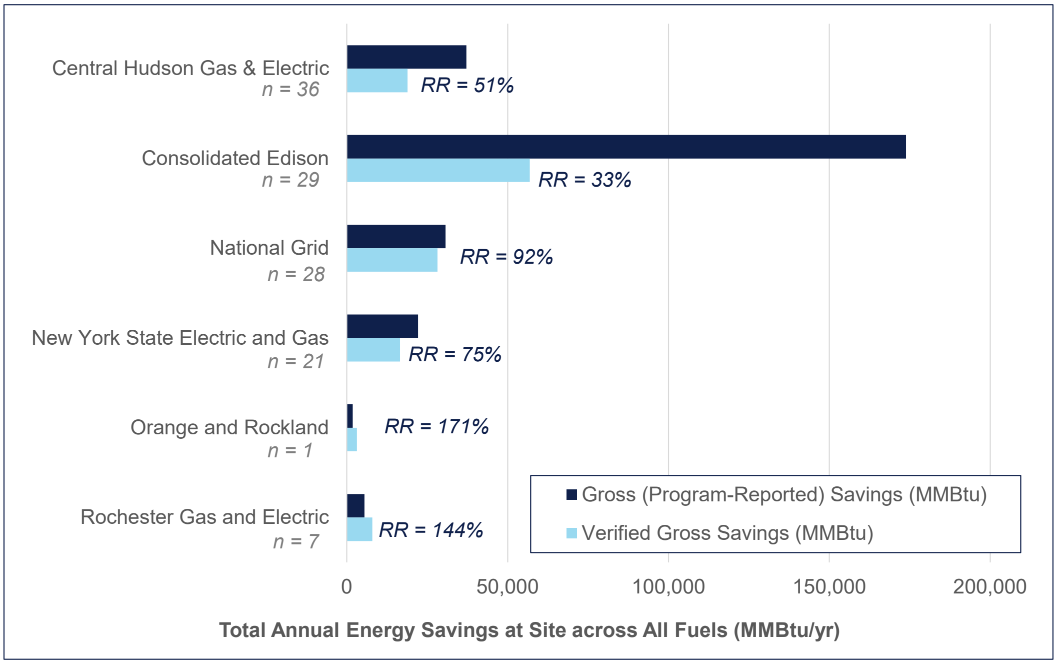


Figure J-3. Combined (ASHP and GSHP) results by event type (sampled projects only)

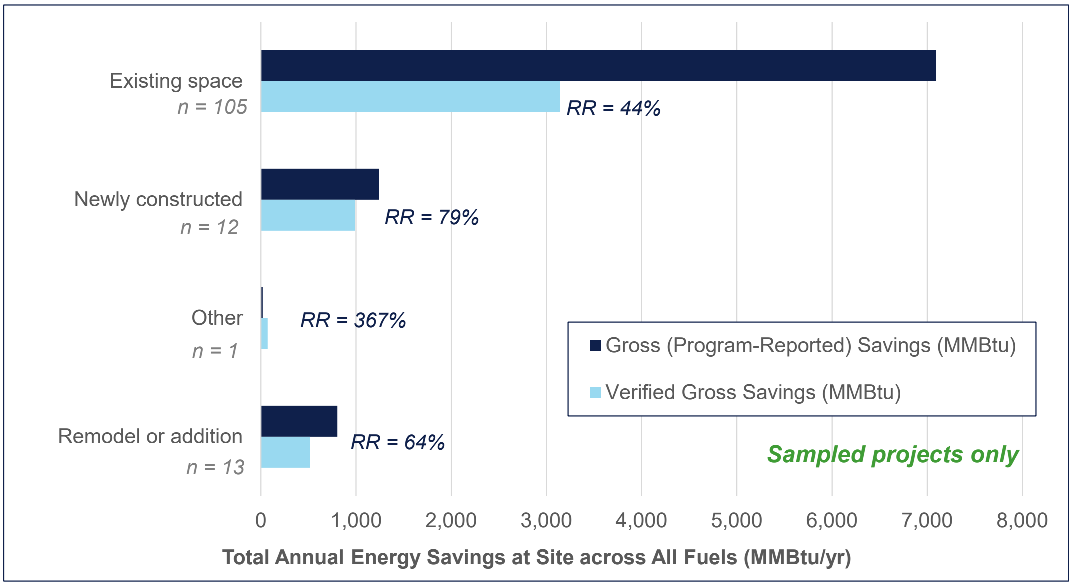


Figure J-4. Combined (ASHP and GSHP) results by evaluator-classified baseline (sampled projects only)

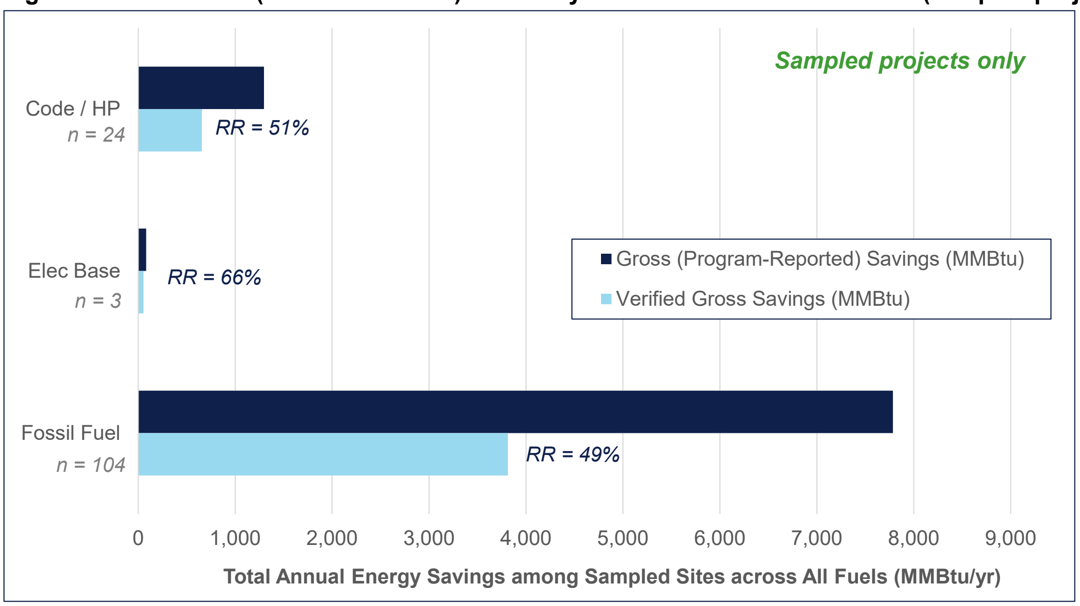
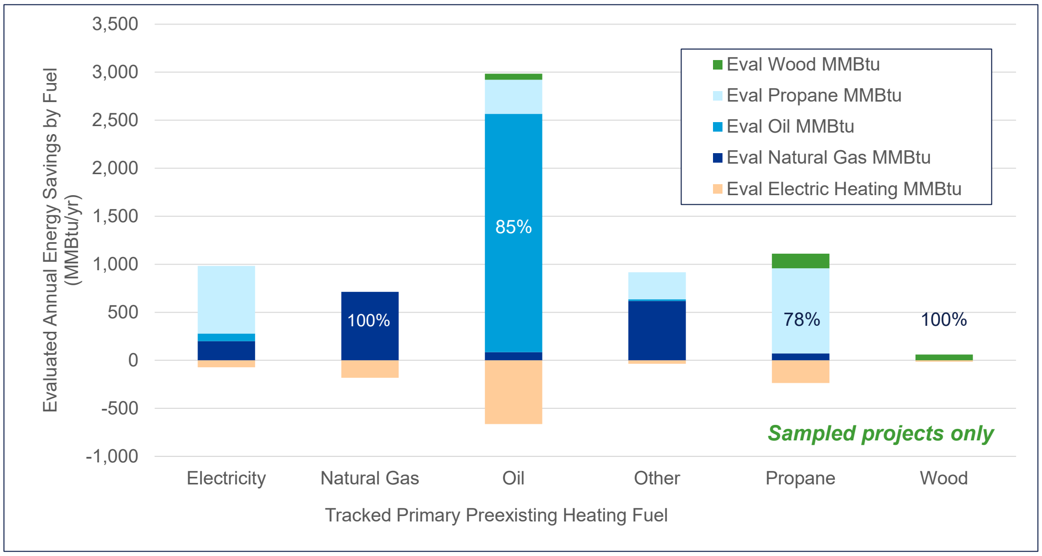


Figure J-5. Combined (ASHP and GSHP) results by fuel by tracked fuel type



ASHP Results

Figure J-6. ASHP results by tracked preexisting heating fuel

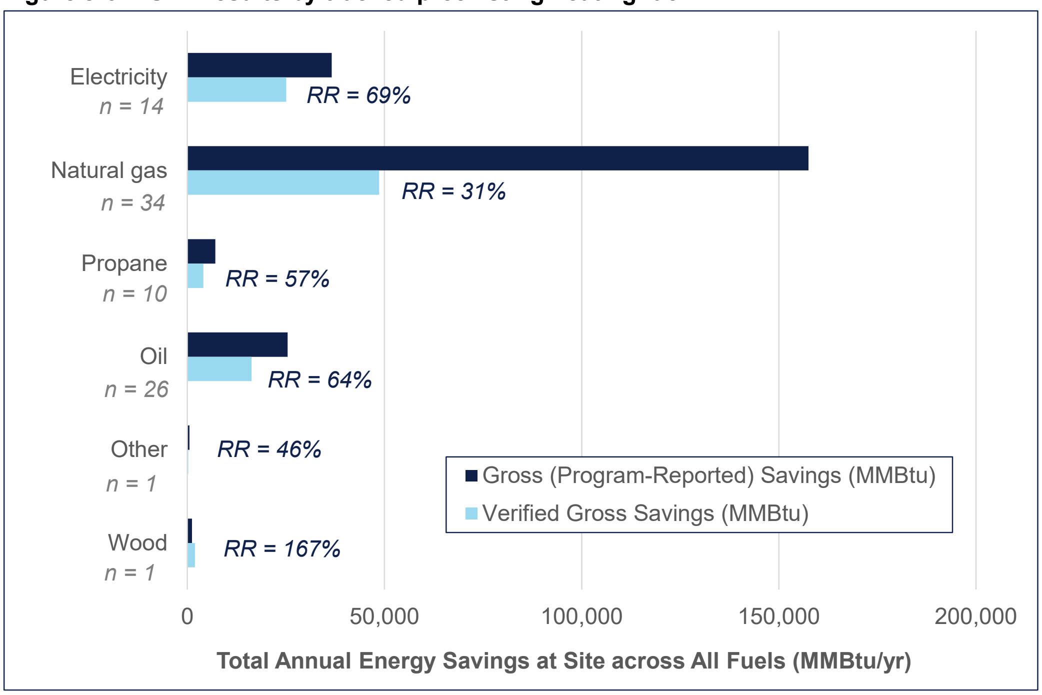


Figure J-7. ASHP results by tracked preexisting heating system type

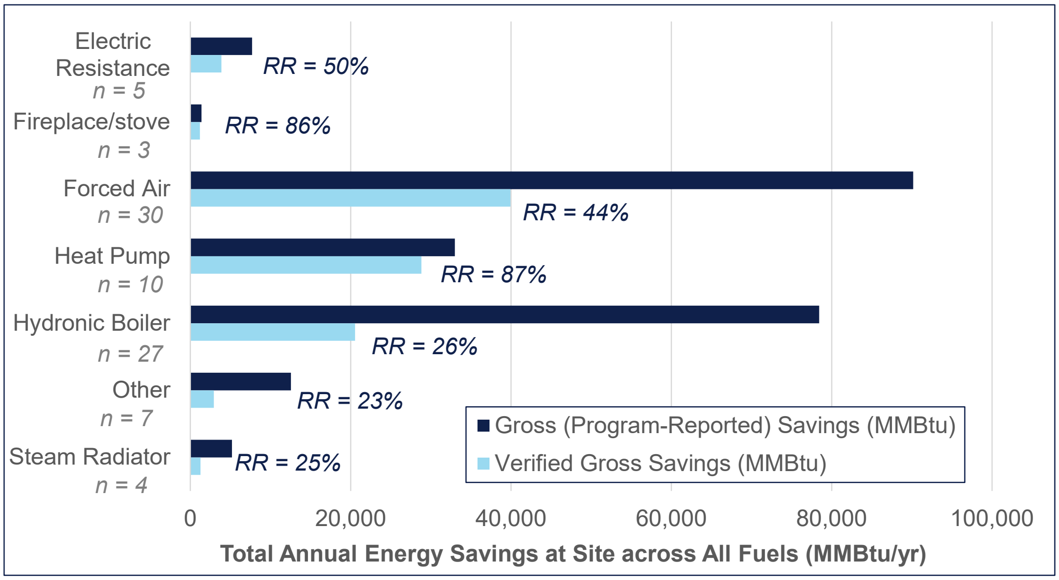
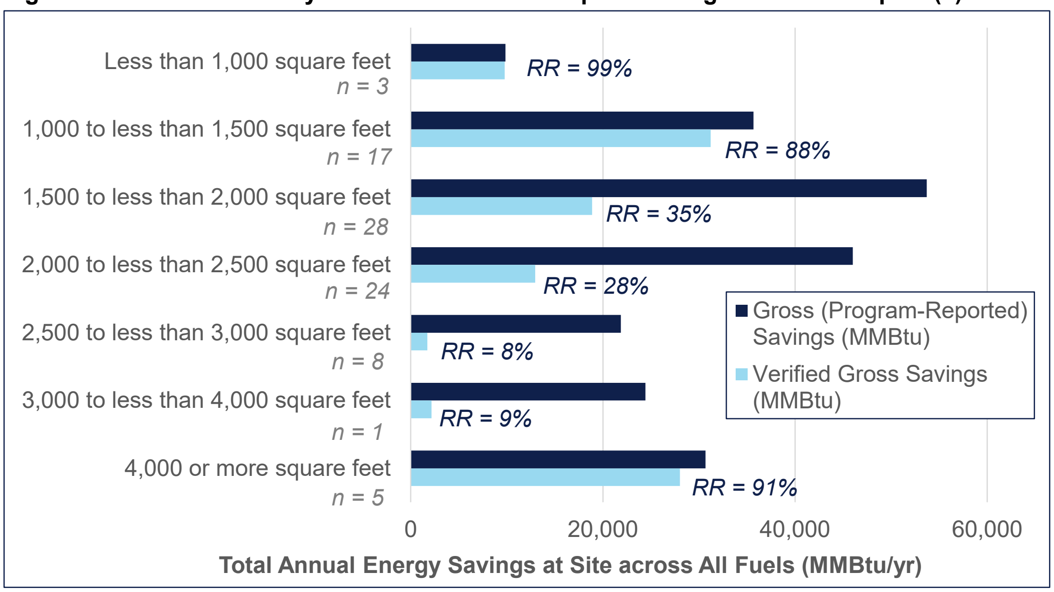


Figure J-8. ASHP results by tracked conditioned square footage of affected space(s)



GSHP Results

Figure J-9. GSHP results by tracked preexisting heating fuel

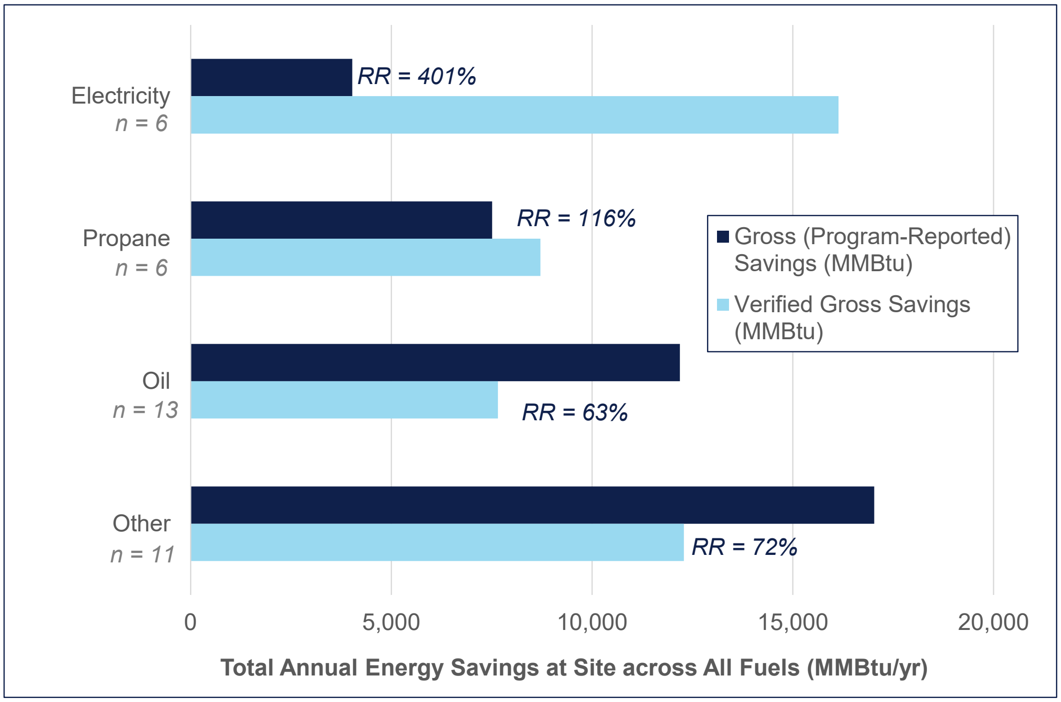


Figure J-10. GSHP results by tracked preexisting heating system type

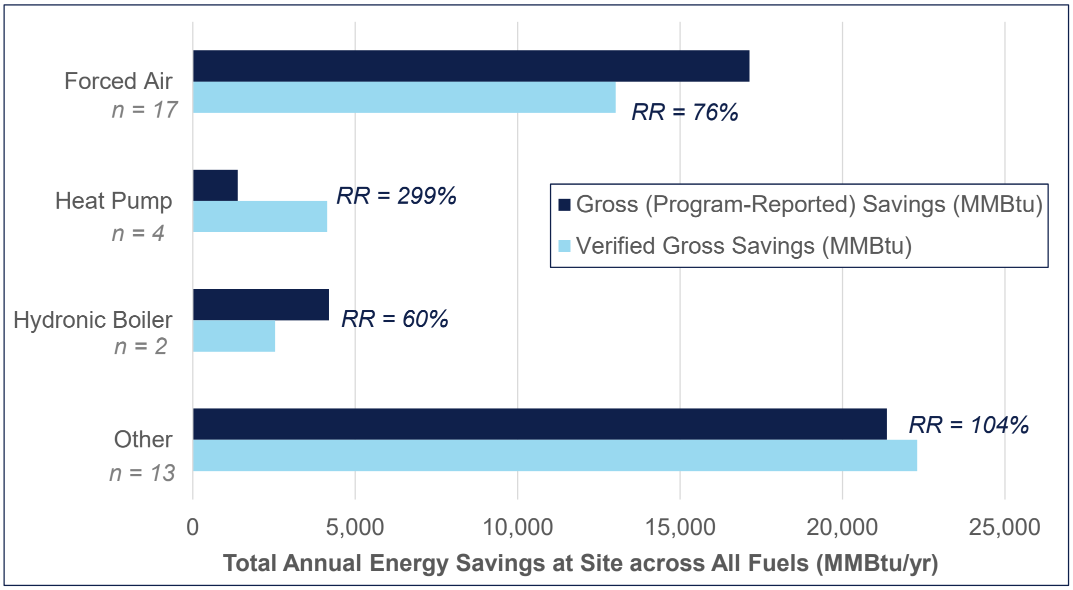
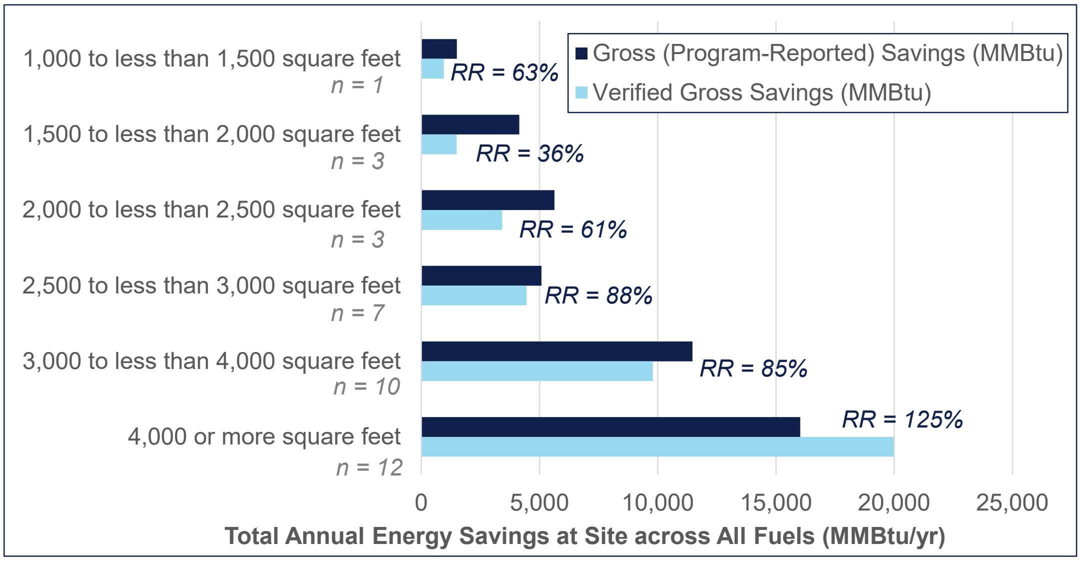


Figure J-11. GSHP results by tracked conditioned square footage of affected space(s)



About DNV

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