# Heat Pump Impact Evaluation

*Final Report*

Prepared for:

**New York State Energy Research and Development Authority**

Albany, NY

Elizabeth Boulton
Tracey DeSimone
Project Managers, NYSERDA

Prepared by:

**DNV**

Corporate Headquarters: Katy, TX

Patrick Hewlett

Director, DNV

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FINAL REPORT

# Heat Pump Impact Evaluation Final Report

## New York State Energy Research and Development Authority

**Date:** April 8, 2022

# Table of contents

## List of figures

## List of tables

## GLOSSARY OF TERMS

**Absolute precision –** Precision is a measure of uncertainty that is standard in the industry. Absolute precision is distinguished from relative precision (see below) as it shows uncertainty in absolute terms as a percentage of 100% VGS realization rate.

**Air-source heat pump (ASHP)** – A reversible system using a vapor-compression refrigeration cycle that extracts heat (in heating mode) and rejects heat (in cooling mode) from outside air. This study involved both ducted and ductless ASHP systems (see below).

**Coefficient of performance (COP)** – 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). The higher the COP, the more efficient the system. Heat pump COPs typically exceed 3-4, as compared with fossil-fuel heating systems with COPs below 1.

**Cold-climate ASHP (ccASHP)** – ASHPs specifically designed to operate efficiently down to temperatures of 0°F or below. ccASHPs achieve efficiencies at low temperatures through the use of an inverter-driven, variable-speed compressor. All ASHPs sampled for M&V in this evaluation are designated as ccASHPs.

**Confidence interval** – When paired with a precision estimate, the likelihood of a sample-based estimate falling within a given range of the true value. For example, for electric energy savings, 90/10 confidence/precision implies that the evaluators are 90% confident that the result falls within ±10% of the true value.

**Core rigor** – The evaluation M&V procedures applied at the majority of sampled sites. Core procedures represent industry-standard approaches and primarily involve amperage and/or power metering of rebated systems.

**Displacement** – In the context of HVAC installations, displacement involves a shift in how a building's heating or cooling load is satisfied among different systems including heat pumps.

**Ductless mini-split heat pump (DMSHP)** – ASHPs that include two separate primary components: an exterior condenser unit for heat extraction/rejection and an interior compressor/evaporator unit that deliver conditioned air directly to given zone(s) without ductwork.

**Early replacement –** A replacement of preexisting, operating equipment that has not reached the end of its effective useful life. The first-year savings (the focus of this evaluation) reflect the efficiency gain from the rebated system as compared with the preexisting *in situ* system.

**Evaluated savings** – The savings estimate independently quantified by the evaluator after the energy impact evaluation has been completed.

**Equivalent full-load hours (EFLH)** – The annual operating hours of a measured system as if the system operated exclusively at 100% load. EFLH is defined as the total energy output of a system divided by its rated capacity.

**Ground-source heat pump (GSHP)** – A reversible system using a vapor-compression refrigeration cycle that extracts heat (in heating mode) and rejects heat (in cooling mode) from groundwater, taking advantage of relatively stable groundwater temperatures year-round.

**Intensive rigor** – The evaluation M&V procedures applied at select sites. Intensive rigor involved laboratory-grade M&V to quantify electric input and energy output of rebated systems to independently assess performance.

**Measurement and verification (M&V) –** The process of planning, measuring, collecting and analyzing data for the purpose of verifying and reporting energy savings within an individual facility resulting from the implementation of energy conservation measures.[1]

**New York Technical Reference Manual (NY TRM)** – New York's joint utilities annually release a technical manual designed to provide a standardized, fair, and transparent approach for quantifying measure-level energy savings. Evaluators relied on various NY TRM Versions for retrospective assessment (Version 5.2[2] active at time of program installations) and prospective context (Version 9[3], currently active).

**Normal replacement –** A replacement of failed equipment or removed equipment that has reached the end of its effective useful life. The first-year savings for such installations reflect the efficiency gain from the rebated system as compared with a code-compliant alternative.

**Realization rate (RR)** – The ratio of evaluated savings and reported savings. Calculated as the total evaluated savings divided by the total reported savings; the result defines what percentage of savings are realized by the program.

**Relative precision** - Precision is a measure of uncertainty that is standard in the industry. For impact evaluations, relative precision expresses uncertainty as a percentage of the verified gross savings (VGS) RR.

**Reported savings** – Project energy savings claimed by NYSERDA and reported to the Department of Public Service (DPS). Reported savings serve as the denominator in the calculation of the realization rate.

**Site** – A physical location at which an energy efficiency project has been implemented.

**Site MMBtu savings** – A consolidated savings value that combines electric energy savings at the customer site (i.e., discounting generation, transmission, and distribution losses) with fossil fuel energy savings.

**Stratified ratio estimation (SRE)** – SRE combines a stratified sample design with a ratio estimator. It facilitates efficient sampling without bias through stratification by project size.

**Verified gross savings (VGS)** – Termed "evaluated gross savings" in prior New York evaluation reports, VGS represent the gross savings adjusted by the program administrators' most relevant savings factors (e.g., Realization Rates (RRs)), as reasonably supported by evaluation measurement and verification (M&V). Gross savings are differentiated from net savings via a net-to-gross ratio that quantifies the influence of the program and its rebates on project decision-making. Net savings are not included in this study's scope.

[1] Definition transcribed from https://evo-world.org/en/m-v/what-is-m-v

[2] New York State Joint Utilities, "New York TRM Version 5.2," effective April 2018. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/TRM%20Version%205.2%20-%20April%202018.pdf

[3] New York State Joint Utilities, "New York TRM Version 9," effective January 2022. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf

# 1 EXECUTIVE SUMMARY

DNV is contracted by NYSERDA to evaluate the energy impacts of heat pumps incentivized by three NYSERDA initiatives through 2018. The evaluated technologies include air-source heat pumps (ASHPs), comprising both ducted and ductless mini-split heat pump (DMSHP) systems, and ground-source heat pumps (GSHPs). Three programs administered by NYSERDA—Underutilized Products (ASHP), Heat Pumps and Solar Thermal (GSHP), and the Heat Pump Pilot Projects Demonstration—distributed rebates to residential and commercial participants that selected eligible heat pump models to partially or fully displace pre-existing or code-compliant heating and cooling systems. From their 2017 inception through 2018—the evaluation timeframe considered for this study—the programs distributed rebates to 4,515 customers and reported savings of 272,546 MMBtu across all energy sources, including electricity (at site[4]), natural gas, and delivered fuels such as propane and fuel oil. These programs are no longer administered by NYSERDA and have been superseded by the NY Statewide Clean Heat program, administered by the state's joint electric utilities. Many of the recommendations from this evaluation of New York's predecessor heat pump programs have been incorporated by the current NYS Clean Heat program.

The impact evaluation was divided into two phases corresponding to the following objectives identified in Table 1-1. Phase 1 included participant surveys, interviews with contractors, and comparison of weather-normalized consumption data between pre- and post-installation periods to determine at-the-meter impacts of the heat pump installations. Phase 2 involved on-site measurement and verification (M&V) of rebated heat pump systems at a sample of participating homes and businesses.

**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[5] | 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 | X |
| Confirm and refine billing analysis through seasonal on-site metering | | X |
| Analyze the effects of COVID on heat pump usage | X | |

## 1.1 Evaluation Methods

In fall 2019, prior to data collection, the DNV evaluation team (or "the evaluators") conducted a literature review and administered in-depth interviews with ten industry experts to inform the evaluation data collection and analysis methodology. The literature review refined the evaluation approach by identifying best practices for measurement and verification (M&V) and analysis of heat pumps. Next, in winter 2019-2020 and spring 2021, evaluators conducted two rounds of Qualtrics-based surveys to assess heat pump characteristics among participating customers. The first occurred after heat pump installation but before the COVID-19 pandemic, while the second focused on customer behavior and heat pump usage during the pandemic. To supplement the perspectives provided by participating customers, evaluators conducted 24 in-depth interviews with installer contractors to collect information on heat pump sales practices, recommendations for quality installations, and observations on operations or maintenance issues.

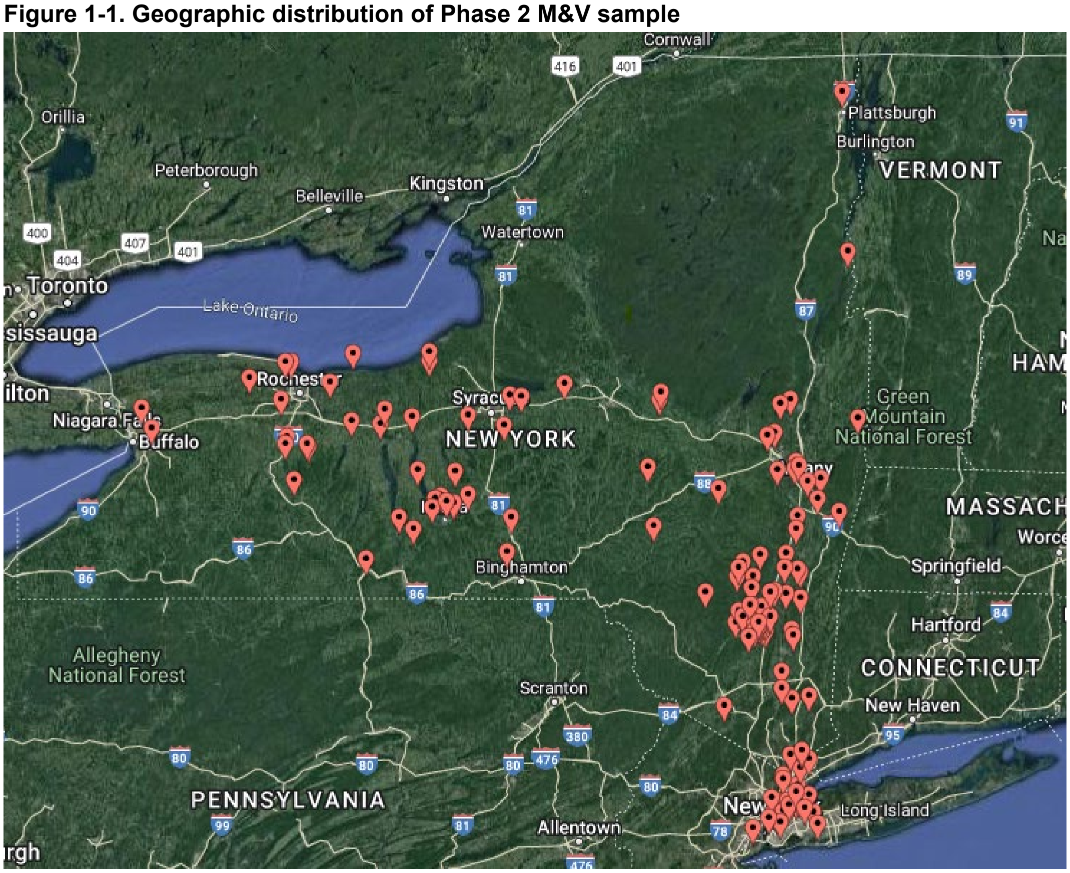
[4] All MMBtu savings in this report reflect *site* MMBtu— i.e., no electric production, transmission, or distribution efficiencies are incorporated.

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

As part of evaluation Phase 1, the evaluation team next requested consumption data for participating homes and businesses after collecting customer authorizations via survey. Consumption data consisted of both utility monthly billing data for electric and natural gas as well as fuel delivery records for unregulated fossil fuels such as propane and heating oil. After organizing and cleaning the collected data, analysts developed pre- and post-installation regressions of energy consumption as a function of historical weather data. Regressions were next applied to typical meteorological data to determine weather-normalized energy consumption before and after the heat pump installation; the difference of these values represents the evaluated savings at the customer meter. Ultimately, evaluators assessed 220 projects using a billing analysis approach. Evaluators summarized Phase 1 results in a memorandum submitted to NYSERDA in spring 2020.

Evaluation Phase 2 involved on-site M&V at a sample of 137 participating facilities from spring 2020 through fall 2021. As illustrated in Figure 1-1, evaluators stratified the Phase 2 sample design by climate zone to ensure geographic representation throughout New York. Field engineers visited each facility to confirm survey responses, verify the installation and operability of rebated heat pumps, and deploy performance monitoring devices on the heat pump and other affected systems. For 125 sites in the sample, the evaluation team executed a “core” rigor approach by deploying remotely communicating amperage loggers on the electrical circuit serving the heat pump(s) and temperature loggers in associated ducts and, for GSHPs, piping. For the remaining 12 sites, evaluators applied an “intensive” rigor approach and deployed power monitoring devices and additional temperature/humidity loggers. The core and intensive M&V approaches were informed by the best practices identified from the preceding literature review. All site visits included spot measurements of relevant systems.

**Figure 1-1. Geographic distribution of Phase 2 M&V sample**



The evaluation analysts processed metered interval data to characterize the heat pump's heating and cooling outputs 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 for the most proximate weather station in New York. To establish the baseline energy consumption, analysts considered pre-existing system types and operating conditions as well as applicable code-compliant alternatives. The difference in annual energy consumption between baseline and installed conditions constituted the evaluated savings and realization rate (RR).[6]

## 1.2 Results

Table 1-2 compares the program-reported savings, inclusive of all fuels including electricity in MMBtu at site, with evaluated savings for ASHP, GSHP, and overall. Results from evaluation Phase 1 and Phase 2 are presented to the right of the program-reported savings as verified gross savings (VGS).[7] Relative precision (RP) is a normalized measure of uncertainty that is standard in the industry. Because some RRs are relatively low in this study, they dramatically inflate the relative precision and appear to suggest a large amount of uncertainty. Table 1-2 includes the absolute precision (AP) as well, which shows the uncertainty in absolute terms as a percentage of a hypothetical 100% VGS realization rate.

**Table 1-2. Comparison of program-reported and evaluated impacts by system type and by evaluation phase**

| | | | Phase 1 Billing Analysis Results | | | | Phase 2 M&V Results | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tech. | N | Gross (Program-Reported) Savings (MMBtu) | Verified Gross Savings (Site MMBtu) | VGS RR[1] | RP @ 90% CI[2] | AP 90% CI[3] | Verified Gross Savings (Site MMBtu) | VGS RR[1] | RP @ 90% CI[2] | AP @ 90% CI[3] |
| ASHP | 4,045 | 228,373 | 62,024 | 27% | 40% | 11% | 87,447 | 38%[4] | 30% | 12% |
| GSHP | 470 | 42,858 | 21,787 | 51% | 16% | 8% | 42,862 | 97% | 16% | 15% |
| **State-wide** | **4,515** | **271,231** | **83,811** | **31%** | **30%** | **9%** | **130,309** | **48%** | **21%** | **11%** |

[1] Verified gross savings realization rate

[2] Relative precision at the 90% confidence interval

[3] Absolute precision at the 90% confidence interval

[4] For 15% of ASHP systems sampled for M&V, customers indicated they would have installed a HP regardless of the influence of the program. Due to complexities in establishing and discounting program influence, which extends beyond the rebate and may include factors such as a more developed contractor base and a more mature supply chain, evaluators calculated gross impacts for such projects by considering each site's most reasonable, code-compliant fossil fuel-fired system as baseline. Evaluators estimate that this baseline treatment increased the ASHP RR by 6%.

Phase 1 analysis of premise-level consumption data showed that the programs realized 31% of claimed MMBtu impacts, with GSHPs outperforming ASHPs with nearly twice as high a RR. Premise-level analysis provided preliminary results on at-the-meter impacts for a broader pool of HP installations (n = 220), accounting for baseline scenarios as informed by the web-based customer survey. But premise-level analysis was limited in explaining the drivers of savings differences and identifying opportunities to improve savings estimates.

[6] The realization rate is the ratio of evaluated savings to program-reported savings.

[7] Termed "evaluated gross savings" in prior New York evaluation reports, VGS represent the gross savings adjusted by the program administrators' most relevant savings factors (e.g., RRs), as reasonably supported by evaluation M&V.

Phase 2 M&V (n = 130[8]) produced granular, equipment-level performance data that demonstrated an overall MMBtu savings RR of 48%, with ASHPs realizing 38% of reported MMBtu savings and GSHPs realizing 97% of reported savings. The primary drivers of the low ASHP realization rate include:

- **Reduced heating operation** – Over the course of a typical year, program-rebated ASHPs provided 44% of the annual heating output assumed within program savings claims. Reduced runtime limited the ASHPs' opportunities for savings as compared with a less efficient and more carbon-intensive baseline. Differences in operation reduced the ASHP RR by 56%. By pairing Phase 2 M&V data with rated capacities by ASHP system, evaluators determined 565 annual equivalent full-load heating hours (EFLHH). As a point of comparison, NY TRM Version 9 recommends a range of EFLHH from 786 to 1,125 for whole-home heating systems depending on region and vintage.
- **Use of preexisting HVAC systems** – Relatedly, 71% of ASHP recipients reported continued use of preexisting HVAC systems, such as fossil fuel-fired boilers or furnaces. Customers that continued to use legacy heating systems achieved 40% lower MMBtu savings than those that removed the legacy systems.
- **Cooling savings** – The program did not claim cooling impacts from ASHP installations. However, evaluators determined that ASHPs led to a 4% increase in evaluated MMBtu savings, as 94% of rebated systems involved replacement of a less-efficient pre-existing cooling system or code-compliant alternative. Phase 2 M&V data showed that ASHPs provide cooling over 434 equivalent full-load cooling hours per year.
- **Near-rated efficiencies** – Through intensive M&V, evaluators determined that ASHPs achieved heating season performance factors (HSPFs) and seasonal energy efficiency ratios (SEERs) 3% and 6% lower than manufacturer ratings for heating and cooling season performance, respectively.
- **Baseline treatment** – For 15% of sampled ASHP systems, customers indicated they would have installed a HP regardless of program intervention. From a coefficient of performance (COP) perspective, HP-to-HP projects limit the amount of achievable savings, as high-efficiency HPs achieve only an incremental COP increase (less than 1 COP point), while fossil fuel-to-HP projects achieve a significantly higher increase of two or more COP points. Due to complexities with establishing the influence of the programs on accelerating the heat pump market in New York, evaluators calculated gross impacts for such projects by considering the most reasonable, code-compliant fossil fuel-fired system as baseline. Evaluators estimate that this baseline treatment increased the ASHP MMBtu RR by 6%.

Evaluators determined that GSHP systems achieved 3% less MMBtu savings than predicted by the program. The 97% GSHP RR was the result of several savings differences that generally offset one another:

- **Reduced heating operation** – GSHPs operate for 2,099 EFLHH, or 84% of the value assumed within the program's savings calculator. This difference reduced the GSHP RR by 16%.
- **Higher annual cooling output** – On the other hand, evaluators determined that GSHPs provide more cooling than assumed within program savings claims, increasing the GSHP RR by an estimated 2%.[9] Phase 2 M&V data showed that GSHPs provide 363 equivalent full-load cooling hours per year.
- **Higher efficiencies** – Through intensive M&V, evaluators determined that GSHPs operated at HSPFs and SEERs 13% and 8% better than manufacturer ratings for heating and cooling season performance, respectively.[10] [11]

[8] Phase 1 and Phase 2 samples partially overlapped. Of the 130 sites analyzed in Phase 2, 37 ASHP and 11 GSHP projects were also included in Phase 1. The evaluators initially explored "nesting" the Phase 2 sample within the Phase 1 pool of analyzed projects; however, difficulties in recruiting customers for Phase 2 M&V during the COVID-19 pandemic reduced the overlap between phases and eliminated the possibility of a nested sampling approach.

[9] Details were limited on the program's supporting assumptions for GSHP cooling savings claims. Evaluators back-calculated the presumed reported cooling savings from available tracking data and found that evaluated cooling savings more than doubled them on average. Nonetheless, GSHP cooling savings are comparatively minor when compared with heating savings—cooling savings comprised 2% of the total evaluated GSHP MMBtu savings per year.

[10] Notably, GSHPs ratings are not comprehensive of the whole heating or cooling season like traditional HSPF and SEER. Rather, manufacturer ratings reflect full-load performance at a specific test condition.

[11] The evaluated HSPF matched the program-assumed HSPF reflected in savings claims within 1%. Details on supporting cooling assumptions were unavailable.

- **Early replacement baselines** – Evaluators determined that approximately half of sampled GSHP projects were early replacements of operable equipment, and achieved first-year savings reflected the efficiency gain as compared with preexisting systems. The program savings claims, on the other hand, more often reflected a code-compliant baseline as a result of normal replacement installations. This difference in baseline treatment led to an estimated 18% increase in the GSHP RR.

Comparison of ASHP evaluation results by phase showed that the Phase 2 equipment-level results (MMBtu RR of 38%) outperformed the Phase 1 premise-level results (MMBtu RR of 27%). This difference is primarily due to the alternative baseline treatment discussed on the prior page. Phase 2 results for GSHPs (RR of 97%) significantly exceeded the Phase 1 premise-level result (RR of 51%). Two factors primarily contributed to differences in evaluated GSHP impacts by phase. First, GSHP projects are typically more complex and therefore more likely to involve nuanced baselines that are most accurately characterized through on-site M&V (as done in Phase 2) than a web-based customer survey (Phase 1).[12] Second, only 11 GSHP projects were assessed in both Phase 1 and Phase 2. Billing analysis attrition, difficulties in recruiting, and a relatively small GSHP recruitment pool limited the evaluators' ability to assess identical sites in both phases of study. The billing analysis pool included 72 more GSHP projects than the M&V sample.

### 1.2.1 Impacts by Fuel

Granular results from evaluation Phase 2 allowed evaluators to examine achieved system-level impacts by fuel, as illustrated in Figure 1-1 for sampled ASHPs. The figure presents evaluated and reported site MMBtu impacts by fuel, with beneficial electrification (i.e., added electric load) illustrated as the leftmost striped bar. MMBtu savings are illustrated by the striped orange (electric energy efficiency savings during heating operation), striped blue (electric savings during cooling operation), and solid bars (various displaced fossil fuels).

The programs applied identical savings assumptions for all ASHP installations in the evaluation population. One such assumption was that all participating facilities consumed #2 fuel oil as the primary heating fuel before ASHP installation. The figure illustrates that ASHP installations offset a broader diversity of fuels as compared with the programs' oil assumption. Additionally, the figure shows the relative contributions of electric savings and penalties between heating and cooling seasons, in contrast with the program's heating-only assumption.

The primary driver of the 38% ASHP MMBtu RR—lower operating hours than reflected within program deemed savings—is evident in the figure. The evaluated bars are noticeably shorter than the reported bars for both beneficial electrification and saved MMBtu.

[12] The on-site data collection form used by field engineers in Phase 2 included a battery of questions related to operability of preexisting HVAC systems, feasibility of their continued use, and the customers' preferred heating and cooling alternatives to HPs absent the influence of the program. These complex questions are more conducive to in-person interviews than a web-based survey and served to establish the baselines used in Phase 2 analysis. 14 GSHP systems in the Phase 2 sample resulted in fossil fuel-fired normal replacement baselines, which led to significantly higher efficiency gains as compared with ASHP baselines.

**Figure 1-2. Evaluated vs. reported ASHP impacts by fuel**

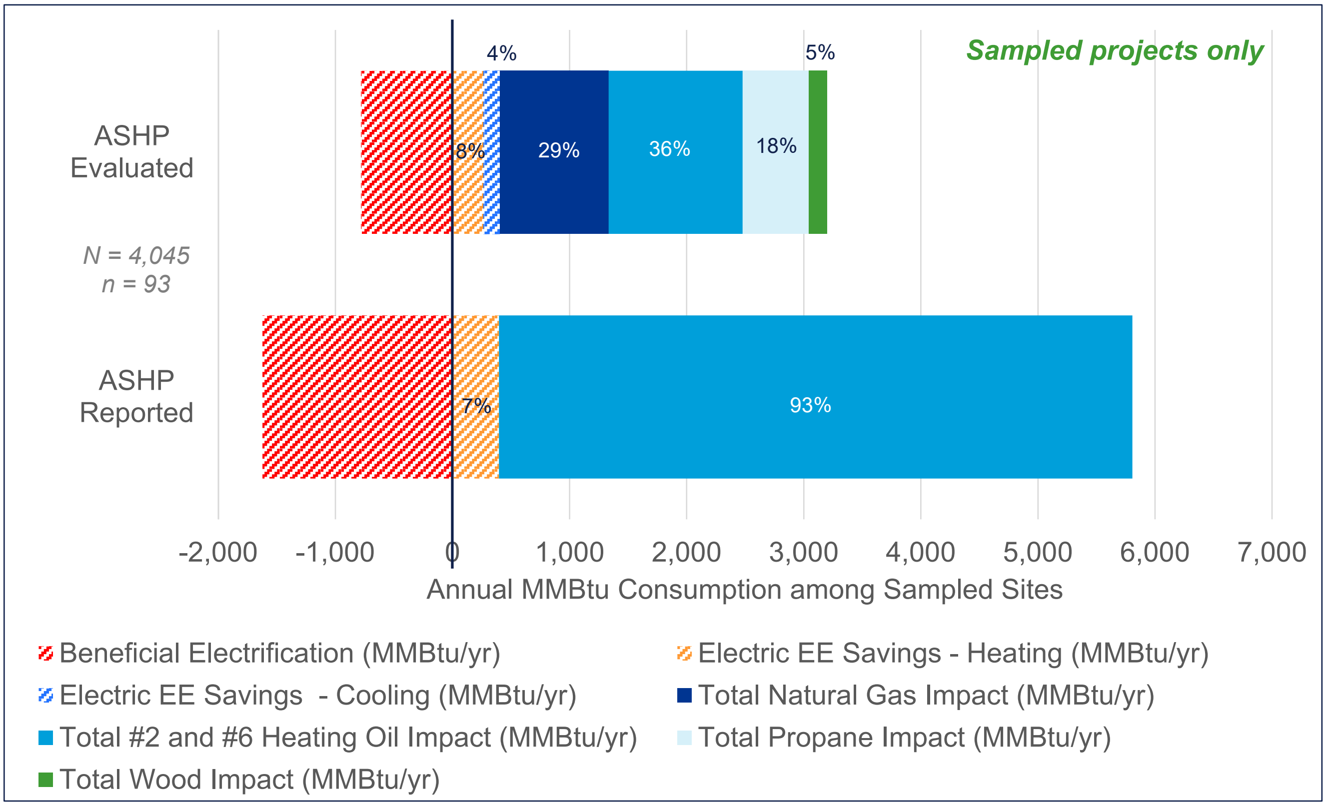
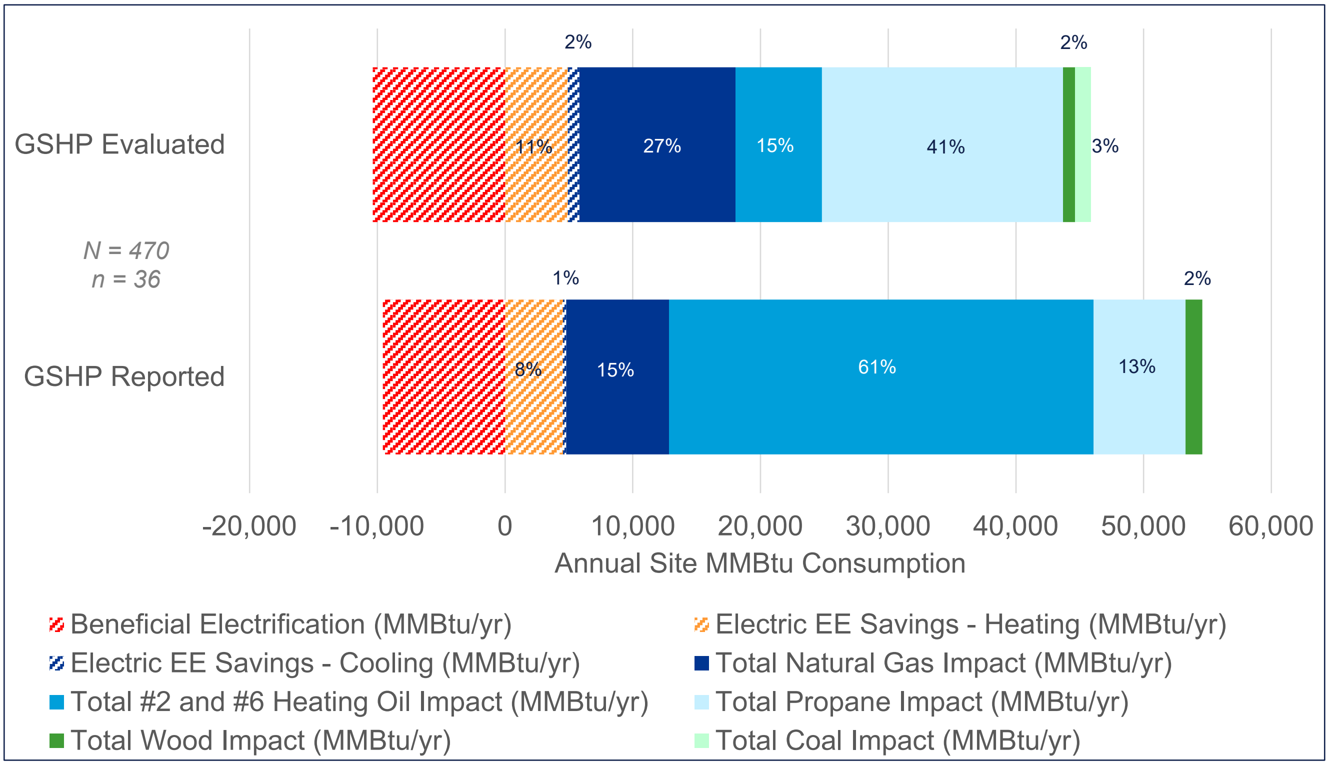



Figure 1-2 similarly illustrates the impacts by fuel for GSHP installations.[13] Unlike for ASHP, the programs claimed fossil fuel savings among natural gas, fuel oils, propane, and wood categories. This allowed evaluators to expand results by fuel from the sample to the full population of 470 GSHP projects. Overall, evaluators determined higher natural gas and propane savings, and lower fuel oil savings, than claimed by the programs.

[13] Despite the overall GSHP RR of 97%, the two bars appear unequal due to fuel-by-fuel differences in RRs and reported savings claims.

**Figure 1-3. Evaluated vs. reported GSHP impacts by fuel**




## 1.3 Conclusions and Recommendations

While the evaluated heat pump programs have been discontinued, the evaluation team has framed the below conclusions and recommendations wherever possible to be applicable to the Clean Heat programs currently administered by New York's joint electric utilities. This forward-looking context has been italicized to distinguish from recommendations specific to the evaluated NYSERDA programs.

***Program Accomplishments***

- **The evaluated programs led to energy savings and carbon emissions reductions.** The Underutilized Products, Heat Pumps and Solar Thermal, and Heat Pump Pilot Projects Demonstration programs led to significant MMBtu savings and offsets of fossil fuels, including 82,516 MMBtu of natural gas, 175,710 gallons of heating oil, and 283,870 gallons of propane. Overall, the realized energy savings offset approximately 7,801 tons of $CO_2$ from fossil fuels.
- **The programs accurately predicted MMBtu impacts from GSHPs.** Evaluated (Phase 2) MMBtu savings for GSHPs correlated with program-reported savings claims within 3%. The programs' customized savings claims, which were based on contractor building heating load estimates and site-specific information on preexisting heating fuel, were generally accurate.
- **The rebated heat pumps performed near rated efficiencies.** Overall, ASHPs performed closely to rated efficiencies, achieving a weighted average heating seasonal performance factor (HSPF) of 11.34. 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. Evaluated GSHP heating performance exceeded manufacturer ratings by 13% due to higher measured groundwater temperatures than assumed in design conditions. During the cooling season, ASHPs and GSHPs operated within 6% and 8% of rated SEER and EER, respectively.

- **Installed heat pumps led to cooling savings when compared with baseline systems.** Approximately half of 137 customers sampled for M&V did not have cooling systems before the heat pump installation. But 90% of those customers indicated they would have installed a mechanical cooling system if they had not participated in the program. Evaluated cooling savings increased the ASHP and GSHP RRs by 4% and 2%, respectively.
- **The programs engaged contractors to act as 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.
- **The rebated heat pumps function properly.** 89% of surveyed customers did not report any operational or maintenance issues with heat pumps. The remaining 11% reported various issues ranging from outdoor unit vibrations to misunderstanding the system control panel.

***Key Evaluation Findings***

- **Billing analysis results underestimated the M&V results for ASHPs.** The ASHP MMBtu savings RR from 97 measurement and verification deployments (evaluation Phase 2) was 11% higher than the RR determined from premise-level consumption data analysis of 128 ASHP projects (evaluation Phase 1). The difference is primarily attributable to the Phase 2 baseline treatment that more frequently defaulted to fossil fuel alternatives. Aligning the baseline treatment between the two phases would have reduced the Phase 2 MMBtu RR to 32%, indicating reasonable prediction from premise-level analysis.
- **Phase 2 evaluated savings significantly exceeded Phase 1 savings for GSHPs.** On the other hand, for GSHPs, M&V results demonstrated 44% higher MMBtu savings as compared with premise-level consumption analysis. Evaluators primarily attribute this difference to revised baselines in Phase 2 as a result of more comprehensive in-person interviews with customers during site visits.
- **Evaluated savings correlate with pre-existing system type and use.** Phase 1 and Phase 2 results demonstrated that savings are most realized when heat pumps are used as the primary heating equipment. Customers that no longer use pre-existing heating equipment achieved a 40% higher RR than customers continuing to use legacy systems.
- **Evaluated savings correlate with climate zone.** ASHP projects performed significantly better in upstate climate zones 5 and 6 as compared with downstate climate zone 4. Evaluators found that downstate ASHPs operated for fewer heating hours than upstate systems for two primary reasons: 1) higher likelihood of downstate customers using pre-existing heating systems, and 2) smaller conditioned square footage. Heating degree days for downstate customers are lower than for upstate customers, but weather was not as significant a factor as partial displacement frequency, customer usage patterns, and unit oversizing. GSHP projects in climate zone 5 achieved higher MMBtu savings than those in climate zone 6 by 43%.
- **Customers are adding cooling comfort to their lifestyle.** The Phase 1 web survey observed that 25% of spaces with a program heat pump installed were adding cooling to previously uncooled space.[14] 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 approximately 6 degrees. This change in temperature is a significant addition of cooling comfort that could reduce energy savings at the meter. Evaluation analysis models presume that setpoint adjustments would have been made to the baseline alternative system as well.

[14] The Phase 2 M&V sample showed a higher share of such customers with at least one *system* that cooled a previously uncooled space.

*Opportunities to Improve Savings Estimates*

- **Evaluated ASHP savings fell short of program-reported estimates.** Program-rebated ASHP installations led to 62% lower evaluated MMBtu savings compared to program-reported values. The key contributors to the 38% RR for ASHPs are summarized in bullets below.
- **Installed heat pumps provide less heating than assumed by the programs.** The primary driver of the ASHP RR is 56% lower annual heating output than assumed within program savings claims. Phase 2 metered data, extrapolated over a full year and correlated with installed equipment capacities, led to 565 average annual full-load heating hours across the ASHP population of projects, of which over 99% involved DMSHPs. While the body of heat pump evaluation research is rapidly growing, other DMSHP studies in the Northeast have shown similar findings of approximately 450 annual full-load heating hours.[15] In the context of the current New York TRM 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. For GSHPs, evaluators determined weighted average FLHs of 2,325 (per installed capacity) or 2,099 (per tracked Manual J building heating load), whereas the program's savings calculator featured FLHs ranging from 2,230 to 2,604.
- **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.
- **A single deemed savings value is not appropriate for heat pump installations.** With ASHPs encompassing 90% of the evaluation population, their results had significant impacts on the program-level VGS realization rates. The programs assumed a single deemed savings value per outdoor unit for all ASHP installations, not accounting for unit size, baseline, displacement share, or climate. The programs' ASHP 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. 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 contributes to significant variability in evaluation results.
    - **Recommendation:** Reflecting the above four conclusions, ASHP savings claims should be based on site-specific baseline fuel, system type if electric, unit size, location, and expected load displacement relative to size. This study's DMSHP results suggest a default displacement factor of 0.3 relative to total building heating load. The current version of the New York TRM[16] provides detailed guidance on estimating heating and cooling loads for partial- and full-displacement installations. Use of either a quasi-prescriptive calculator, or deemed savings options based on displacement fraction, would markedly improve savings estimates. Crucial to the success of this recommendation is contractor training and oversight to ensure that installed systems are right-sized and credibly characterized based on the portions of heating and cooling loads to be satisfied by the heat pumps. *Based on the evaluators' review of its program manual, the Clean Heat Program requires administering utilities to abide by the current New York TRM. When an installation is not covered by a prescribed measure in the TRM, the program requires a custom track.* [17]

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[15] Massachusetts and Rhode Island Electric and Gas Program Administrators. 2016. "Ductless Mini-Split Heat Pump Impact Evaluation." <http://www.ripuc.ri.gov/eventsactions/docket/4755-TRM-DMSHP%20Evaluation%20Report%2012-30-2016.pdf>

[16] New York State Joint Utilities, "New York TRM Version 9," effective January 2022. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf

[17] New York State Joint Utilities, "NYS Clean Heat Statewide Heat Pump Program Manual Version 5," October 2021. https://saveenergy.ny.gov/NYScleanheat/assets/pdf/NYS-Clean-Heat-Program-Manual.pdf

- **Quantifying evaluated impacts by fuel proved difficult.** For all ASHP installations, the programs claimed all fossil fuel savings as oil, limiting the evaluators' ability to expand evaluation results from the sample to the population of projects. Among 86 ASHP projects in the evaluation sample, we found that program-rebated installations led to a diversity of savings by fuel, including natural gas (comprising 29% of total MMBtu savings across all fuels), fuel oils (36%), propane (18%), and wood (5%). For GSHP installations, the program claimed a broader diversity of fuel-specific savings, though evaluators determined higher shares of natural gas and propane, and lower shares of fuel oils, than claimed.
    - **Recommendation:** Heat pump savings claims should distinguish among different displaced heating fuels as documented by the installation contractor. Fuel-specific impacts are critical for measuring program success versus statewide carbon emissions reduction goals. A single installation might displace more than one heating fuel; therefore, approved contractors should be trained to collect defensible information on pre-existing heating fuel types and shares. When feasible, utility-led programs should leverage historical natural gas consumption data at the participant address to corroborate the tracked estimates for pre-existing natural gas systems.
- **A minority of participating customers would have installed heat pumps regardless of the program.** For 15% of rebated ASHPs, customers indicated via in-person interviews that they would have installed heat pumps regardless of program intervention. Heat pump baselines reduce the achievable savings significantly, as heat pumps can satisfy heating loads much more efficiently than fossil fuel- or resistance-based systems. Due to complexities with establishing the influence of the programs on accelerating the heat pump market in New York, evaluators calculated gross impacts for such ASHP projects by considering the most reasonable, code-compliant fossil fuel-fired system as baseline. Evaluators acknowledge that these predecessor heat pump programs likely included early adopter participants whose decision-making might not be representative of future heat pump program participants.
    - **Recommendation:** For heat pump installations in new construction or end-of-life scenarios, savings should be informed by the customers' preferred alternative systems and fuel choices in the absence of the program. While accounting for program influence will continue to be a challenge, evaluators recommend that future heat pump installations comport with the guidance in the active New York TRM.[18] Eligible Program tracking databases should intake relevant site-specific variables and triangulate the most appropriate baseline against which new construction or end-of-life performance is measured.
- **Evaluators observed a small share of GSHP-to-GSHP installations.** During the evaluation planning process, evaluators identified that an additional 20 GSHP installations in the population involved replacement of existing GSHP systems. These projects were removed from the evaluation sampling frame. The New York TRM currently does not accommodate a GSHP baseline.[19]
    - **Recommendation:** GSHP-to-GSHP replacements should be considered as a prescribed scenario by the New York TRM Committee, as the team expects this to become more common as first generation GSHPs begin to reach their effective useful life. *The Clean Heat Program does not appear to accommodate such a baseline, though new construction GSHP projects are required to be submitted through a custom track.*

[18] NY TRM Version 9, active at the time of this writing and referenced below, states that "The baselines used in [the ASHP] measure are determined by the type of equipment that would have been installed without the influence of the program supporting the installation of this measure."

[19] New York State Joint Utilities, "New York TRM Version 9," effective January 2022. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf

- **A majority of participants continued to use pre-existing HVAC systems.** The Phase 1 web survey found that approximately 75% of program participants continued to use pre-existing heating and cooling systems after heat pump installation. These partial displacement scenarios reduce the achievable savings as demonstrated by lower-than-expected outputs and full-load hours as described above.
  - **Recommendation:** Program administrators should consider a tiered incentive approach that rewards full-displacement installations. Training and requiring approved contractors to credibly collect and track this information is crucial to the success of this recommendation.
  - **Recommendation:** Programs should reward partial-displacement installations that include integrated controls that manage heat pump use with legacy systems. There may be limitations to the ability of controls on older pre-existing systems that will need to be acknowledged in such an effort. *Based on the evaluators' review of its program manual, the Clean Heat Program has established nine installation categories with varying incentive structures and eligibility criteria that distinguish among system types, partial- and full-displacement installations, and inclusion of integrated controls.*[20]
  - **Recommendation:** Programs should educate eligible contractors and participating customers on the best practices for optimal heat pump usage, particularly for installations that supplement existing heating systems. Heat pump adoption and savings potential rely heavily on customer awareness of heat pump benefits and their ability to satisfy heat loads during extreme winter temperatures. *The Clean Heat Program manual recommends continuous contractor training, and its website includes a list of educational resources for participating contractors.*[21] *It is unclear if or how the program administrators ensure that contractors review such resources.*

***COVID Implications***

- **COVID has led to higher energy usage per customer.** Total customer-level 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 represented less than 1% of the total energy usage, monthly billing analysis may not be sensitive enough to detect these smaller changes in cooling load.

  Relatedly, 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.
- **Most customers have not adjusted their comfort preferences during COVID.** 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 setpoint saw a direct correlation in an increase in their heating load (3.6 MMBtu or 14% increase in heating load).

[20] New York State Joint Utilities, "NYS Clean Heat Statewide Heat Pump Program Manual Version 5," October 2021. https://saveenergy.ny.gov/NYScleanheat/assets/pdf/NYS-Clean-Heat-Program-Manual.pdf

[21] https://saveenergy.ny.gov/NYScleanheat/resources/

# 2 INTRODUCTION

This report describes the methods and results of the impact evaluation of NYSERDA's heat pump (HP) programs from inception through program year (PY) 2018. The report is comprehensive of all evaluation phases, each of which has previously been summarized in interim memoranda delivered by the evaluation team:

- Preliminary literature review findings and recommendations were addressed in a memo submitted to NYSERDA on February 3, 2020.
- Phase 1 billing analysis methods and results were addressed in a memo submitted to NYSERDA on April 17, 2020.
- Phase 1 survey results, including response data from customers and installers, were addressed in a memo submitted to NYSERDA on December 8, 2020.
- Phase 2 M&V methods and results (heating season only) were addressed in a memo submitted to NYSERDA on September 20, 2021.
- Impacts from COVID-19 on participating customers' behavior and HP usage were addressed in a memo submitted to NYSERDA on December 14, 2021.

Each of the interim memoranda have been included as an appendix to this report. When different, the results presented in the report body supersede the previously submitted interim results.

## 2.1 Program Background

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.[22] The NYSERDA-run programs distributed rebates to residential and commercial participants that selected eligible heat pump models to partially or fully displace pre-existing heating and cooling systems. Rebated installations occurred throughout New York within the territories served by the state's joint electric utilities: Central Hudson Gas and Electric, Consolidated Edison, National Grid, New York State Electric and Gas, Public Service Enterprise Group (PSEG) Long Island, Orange and Rockland Utilities, and Rochester Gas and Electric.

From inception through 2018—the evaluation timeframe considered for this study—the programs reported savings of 272,546 MMBtu (at site[23]) across all energy sources, including electricity, natural gas, and delivered fuels such as propane and fuel oil. ASHPs, which include both ducted systems and ductless mini-split heat pumps (DMSHPs), accounted for 84% of total reported MMBtu savings across 4,045 installations. 470 GSHP installations accounted for the remaining 16%. DMSHPs comprised over 99% of ASHP installations and MMBtu savings.

The evaluated programs are no longer administered by NYSERDA and have been superseded by the NY Statewide Clean Heat program, administered by the state's joint electric utilities. Many of the recommendations from this evaluation of New York's predecessor heat pump programs have been incorporated by the current NYS Clean Heat program.

[22] Projects sponsored through the Pilot Projects Demonstration did not include program-reported savings claims and therefore do not affect the RRs presented in this report.

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

## 2.2 Evaluation Objectives

This evaluation study assesses the performance and energy impacts of ductless mini-split and centrally ducted ASHPs and GSHPs incentivized by NYSERDA through 2018. The impact evaluation is divided into two phases corresponding to the objectives identified in Table 2-1.

**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[24] | 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 | X |
| Confirm and refine billing analysis through seasonal on-site metering | | X |
| Analyze the effects of COVID on heat pump usage | X | |

This report presents methods and results corresponding to each evaluation objective:

- **Evaluate annual gross energy impacts of ASHPs and GSHPs**. Through the billing analysis and M&V methodologies described in Sections 3.5 and 3.6, respectively, evaluators quantified program impacts among electric, natural gas, fuel oil, and propane fuel sources. Section 4 explores and compares results between the two evaluation approaches.
- **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. For 137 customers in the M&V sample, DNV field engineers confirmed or refined the survey information while on site.
- **Characterize seasonal usage of ASHPs and GSHPs**. Equipment-level M&V data allowed 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. The evaluation team analyzed results among different segments of interest to identify trends in performance.
- **Characterize equipment issues that impact performance**. Using metered data and participant survey responses, evaluators identified reasons for deviation between evaluated and reported impacts.
- **Collect information on refrigerant.** In Phase 1, the evaluation team explored trends in refrigeration types within in-depth interviews with participating installers. In Phase 2, evaluators collected site-specific data on refrigerant types among the rebated systems.
- **Confirm and refine billing analysis through seasonal on-site metering.** Section 4.4 compares evaluation results between Phase 1 billing analysis and Phase 2 M&V to identify the benefits and risks of each evaluation approach.
- **Analyze the effects of COVID on heat pump usage.** The evaluation study commenced in Q4 2019 prior to the COVID-19 pandemic. The study therefore allowed comparison of premise-level consumption data, either from utilities or fuel suppliers, between pre-COVID and COVID-affected periods. This analysis provided insights on how COVID affected customer occupancy and heat pump usage patterns.

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

# 3 METHODOLOGY

This section describes the methods used to evaluate the impacts and participant characteristics of NYSERDA's three HP programs through 2018.

## 3.1 Data Sources

During the kickoff phase in Q4 2019, the evaluation team requested several data sources to inform the evaluation sample design and data collection approaches. As survey data and bill authorizations were collected, additional data was requested to inform the analysis. Each of the key data sources is summarized in Table 3-1.

**Table 3-1. Summary of evaluation data sources**

| Data Source | Data Provider | Phase 1 Billing Analysis | Phase 2 M&V | Description |
|---|---|---|---|---|
| Program tracking data | NYSERDA | X | X | Program tracking data formed the basis of the evaluation dataset of record from which statistical samples were drawn. |
| Customer contact data | NYSERDA | X | X | Program tracking data included customer names, addresses, phone numbers, and email addresses for survey engagement and site visit scheduling. |
| Installer contact data | NYSERDA | X | | DNV requested contact information to conduct in-depth interviews with participating installers. |
| Utility consumption data | Utilities (via NYSERDA and customer authorizations) | X | X | After receiving customer authorizations via survey, DNV requested pre- and post-installation electric and natural gas consumption data from utility providers. |
| Delivered fuels data | Fuel suppliers (via APPRISE and customer authorizations) | X | X | Some participating customers used propane, fuel oil, or wood as heating sources before or after the project. APPRISE collected delivered fuels data from suppliers after DNV received customer authorizations. |

## 3.2 Literature Review

Prior to conducting data collection, the evaluation team conducted a literature review and administered in-depth interviews with industry experts to inform the evaluation data collection and analysis methodology. DNV reviewed ten sources as part of the literature review. In-depth interviews involved hourlong phone conversations 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.

Appendix A includes a copy of the literature review memo delivered to NYSERDA on February 3, 2020. DNV incorporated the key findings and recommendations from the literature review and interviews, as summarized in the following two sub-sections, in the data collection instruments and analysis tools described later in this section.

### 3.2.1 M&V Best Practices

- **Long-term amperage metering** of heat pump equipment is necessary and represents standard practice for on-site heat pump metering.
- **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.
- Evaluators should collect **detailed nameplate and configuration data** including capacities, staging, control points, installation date, and thermostat setpoints and setbacks.
- Evaluators should 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.
- For sites using batch delivered fuels (e.g., fuel oil, propane, wood, pellets), evaluators should **collect fuel delivery data** 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, evaluators should **collect trend data** for up to 1 year of operation should be collected for comparison and corroboration with metered data.
- For high-rigor (intensive) sites, evaluators should collect **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 intensive sites, evaluators should collect **additional long-term metering** to provide more data about the in-situ operating efficiency:
    - Temperature metering of the space temperature and supply air temperature,
    - Power metering, rather than amperage metering, of the heat pump system,
    - 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,
    - For GSHPs, supply and return ground source loop temperatures and separate sub-metering for pump power.

### 3.2.2 Analysis Best Practices

- 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.
- For displacement applications where only part of the pre-existing 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.
- 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.

## 3.3 Customer Surveys

DNV conducted two rounds of Qualtrics-based surveys to assess heat pump characteristics. The first occurred after heat pump installation but before the COVID-19 pandemic, while the second focused on customer behavior and heat pump usage during the pandemic.

### 3.3.1 Post-Installation Survey

DNV administered the first customer survey in Q4 2019 to collect information on installed heat pump characteristics and use patterns, customer demographics, and utility account information. Evaluators attempted a census by inviting all 4,515 participating 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 program-rebated heat pumps are used and how much they are displacing heating and cooling loads served by existing HVAC equipment. Additionally, the survey provided key participation paths for future 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 gauged their interest in participating in future on-site monitoring.

To encourage survey participation, DNV offered a $15 gift card for survey participation and an additional $35 gift card for providing utility and fuel delivery account numbers and data authorizations. After initial data cleaning to remove incomplete and duplicate responses, the survey received 775 complete responses, with 448 agreeing to provide utility data authorization. Appendix B provides a copy of the survey instrument; Appendix D includes additional information on survey responses.

### 3.3.2 COVID Behavior Survey

DNV administered a follow-up customer survey in Q1 2021 to assess the effects of the COVID-19 pandemic on customer behavior and heat pump usage patterns. Evaluators reengaged the 775 respondents to the first survey to further understand how the pandemic has impacted their occupancy patterns and heating or cooling set-point preferences. Additionally, the survey collected information on space modifications or other non-routine events that affected billed energy consumption. Similar to the first round, the survey collected customer authorizations to request utility and delivered fuel account information. DNV attempted to reach all 775 prior participants by either email or letter, offering similar incentives as with the first customer survey. Ultimately, DNV received responses from 362 of 775 prior participants. Appendix H provides a copy of the survey instrument; Appendix I includes the interim memorandum of COVID survey results.

## 3.4 Installer Interviews

To supplement the perspectives provided by participating customers, DNV conducted 24 in-depth interviews with installer contractors to collect 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.

DNV interviewed installers in Q2 and Q3 of 2020. The ongoing pandemic delayed many interviews, as participating firms were intermittently shut down or difficult to contact. DNV attempted to contact all 65 installation contractors that assisted with NYSERDA-rebated installations over the evaluation timeframe. Of the 24 interviewed installers, 21 reported that they install

ASHPs, 10 reported that they install GSHPs, with 7 reporting that they install both system types. Fifteen of the 24 installers shared their approximate number of heat pump installation projects per year (approximately 200 on average). Eleven of the 24 installers indicated that their firms only offer heat pump solutions.

Section 4.1.2 examines the results of the installer interviews. Appendix C includes a copy of the installer interview script.

## 3.5 Phase 1 Billing Analysis

After cleaning and processing the customer survey data, the DNV 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 natural 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 3-2 illustrates the fuel supplier data collection efforts.

**Table 3-2. 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%** |

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 five-parameter change point model. For fossil fuels and sites with electric heating or cooling but not both, three-point models apply. See Appendix E 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.

Appendix E describes the cleaning and analysis process in detail.

### 3.5.1 Billing Analysis Attrition

The DNV team reviewed and cleaned each site based on the requirements presented in Table 3-3. After receiving 488 customer data authorizations through the survey, a range of 172 – 310 sites were eligible to be analyzed via billing analysis depending upon the filtering criteria applied, which represents a 35%–64% 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 3-3. 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<br>314 –- 310 | 18<br>16 – 20 | 7 – GSHP sites replacing existing GSHP systems |
| Post-installation electric bills meet sufficient actual read requirements | 304<br>306 – 310 | 8<br>8 – 0 | 8 – Post electric bills >50% estimated |
| All tier-specific statistics tests are met | 220<br>172 – 310 | 84<br>134 – 0 | 9 – Fails statistics tests |
| **Total[1]** | **220**<br>**172 - 310** | **4,293**<br>**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.

### 3.5.2 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.[25] In consultation with West Hill Energy & Computing, who served as the oversight contractor for Phase 1, and NYSERDA, the team developed three analysis filtering scenarios to present a range of evaluated results. Each scenario incorporates increasing levels of strictness regarding data cleanliness, statistical significance, and weather dependency. This Phase 1 analysis is intended to be a preliminary result of the impacts of rebated heat pumps. The Phase 2 results provide more definitive savings per site.

[25] $R^2$ 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 3-4 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 Table 3-4 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 four 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 3-4 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 Appendix E. 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 modeled approach partially or fully. These values sum to greater than 100% because sites with multiple fuels (e.g., electric and natural gas) could use both analysis methods, each applied to a different fuel (e.g., electric analyzed using billing analysis and natural gas analyzed using modeled analysis).

**Table 3-4. Filtering criteria for pre- and post-installation electric and fossil fuel data**

| 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.

### 3.5.3 COVID Impacts Analysis

As part of the COVID behavior survey described in Section 3.3.2, DNV collected utility data authorizations to extend the billing dataset beyond March 2020. The team prepared batch data requests for submission in the Electronic Data Interchange (EDI) for electric and natural gas billing data. 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 utility meters requested. For delivered fuels, DNV with support from APPRISE collected 43 of 61 requested accounts to extend the delivered fuels data beyond March 2020.

To analyze the impact of COVID on customer behavior and heat pump usage, DNV applied similar cleaning and filtering techniques as described in the prior section. Ultimately, DNV analyzed impacts from 184 retained sites after excluding 121 due to missing or anomalous data, residents who had moved, or the presence of solar PV. Appendix I includes additional detail on the COVID impact analysis methodology.

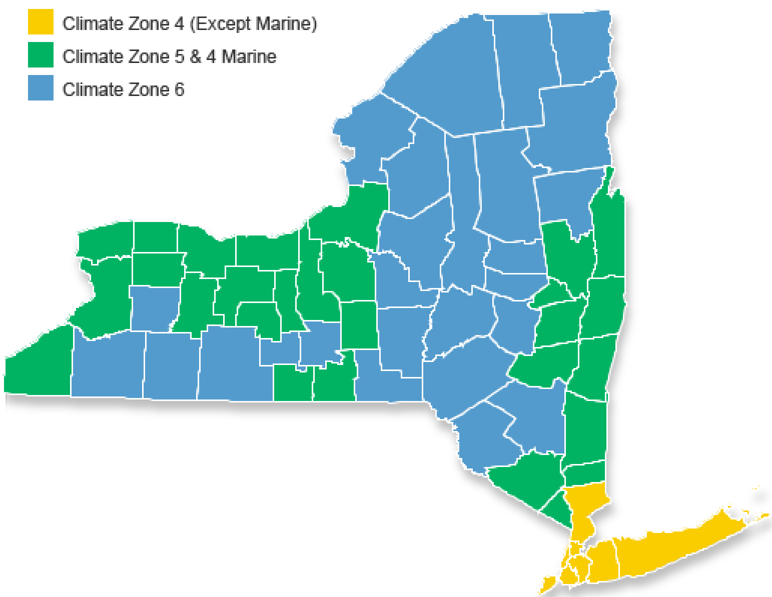
## 3.6 Phase 2 M&V

This section describes the sampling and data collection methods used to assess equipment operation and performance through measurement and verification.

### 3.6.1 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 3-5. 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 3-5 provides the Phase 2 M&V sample design among the 588 available respondents, stratified by equipment type, climate zone, and customer type.

**Table 3-5. Phase 2 M&V sample design based on Phase 1 survey respondents**

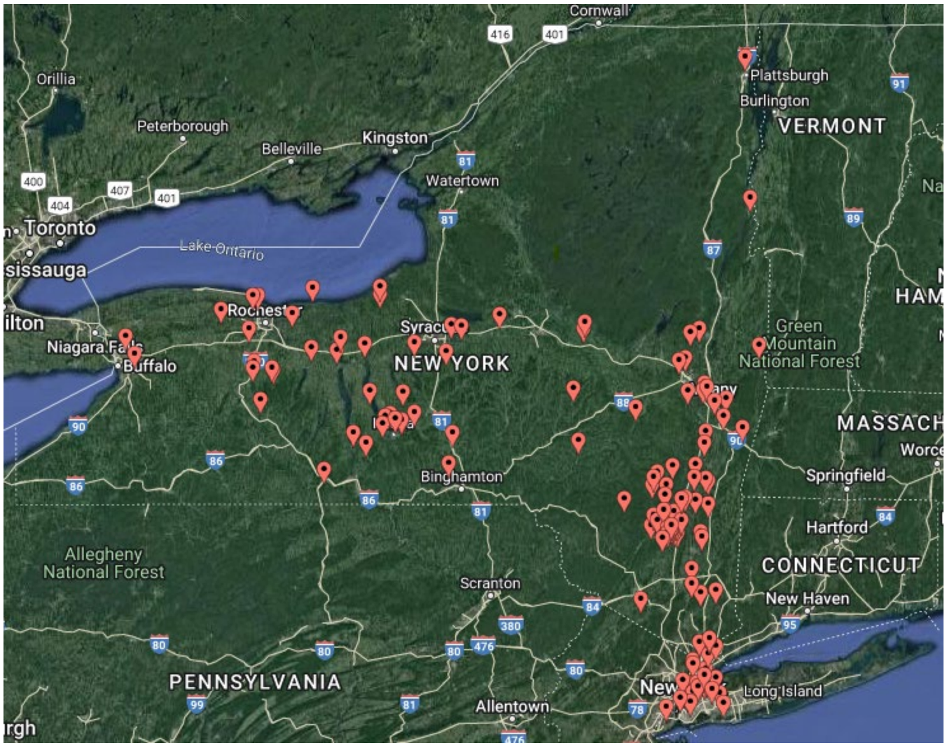
| Tech. | Equip. Sub-Type | CZ | Customer Type* | Pop. | Available Respondents (On-Site Pool) | On-Site Target | Detailed Target | Implied Approximate Relative Precision | Final Completed Count |
|---|---|---|---|---|---|---|---|---|---|
| ASHP | **ASHP Total** | | | **4,043** | **383** | **97** | **97** | **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 |

| 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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |
| | | 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.

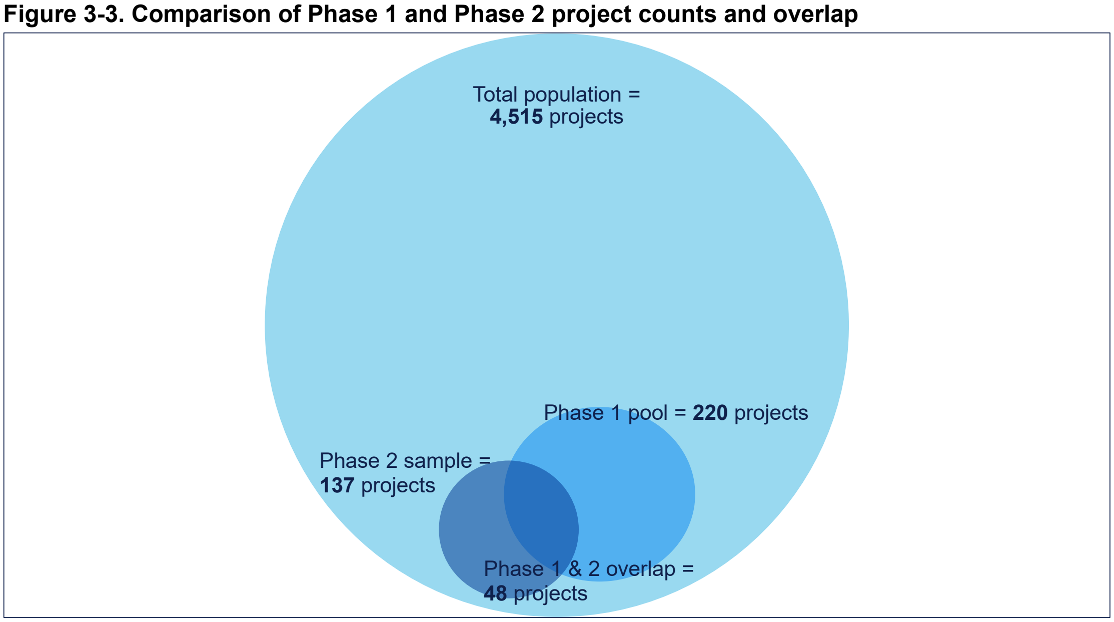
Despite the initial interest of the 588 surveyed participants, many hesitated to participate in the Phase 2 metering portion of the study due to concerns about in-home visits during the COVID-19 pandemic. Downstate respondents were particularly reluctant. Nonetheless, evaluators reached the total sample target of 137, albeit with segment-specific variation between targeted and completed counts for DMSHPs. Figure 3-2 illustrates the geographic distribution of the Phase 2 sample.

**Figure 3-2. Geographic distribution of Phase 2 M&V sample**




Due primarily to analysis filtering discussed in the prior sections, customers sampled for Phase 2 M&V partially overlapped with customers included in Phase 1 billing analysis, as illustrated in Figure 3-2. Evaluators initially explored the possibility of statistically “nesting” the Phase 2 sample within the Phase 1 pool of analyzed projects. Due to the recruitment difficulties explained above, the nested sampling approach was not possible.

**Figure 3-3. Comparison of Phase 1 and Phase 2 project counts and overlap**




Additional information on the M&V sample design is included in Appendix F.

### 3.6.2 Field Data Collection

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.

#### 3.6.2.1 Customer Interview and Walkthrough

For all sampled sites, the field engineer conducted an interview with knowledgeable site 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. For normal replacement or new construction/expansion projects, the on-site interview also sought information on the customer's preferred alternative heating and cooling systems absent program influence.

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 pre-existing 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. When necessary, results from metered heat pumps were applied to unmetered heat pumps based on collected information on room types and usage patterns.

#### 3.6.2.2 Core Rigor

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 pre-existing and/or auxiliary HVAC equipment (e.g., the combustion air fan for a pre-existing boiler still in operation)[26]
- When relevant, 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

[26] Field engineers encountered occasional limitations when attempting to meter auxiliary equipment. In some cases, the equipment was successfully metered but not directly relevant in the analysis. For example, amperage data from supplementary heating devices provided information on other heating output contributions, but ultimately the evaluated savings are based on the amperage and Btu output of the rebated systems. This approach accommodated the partial-displacement scenarios that were prevalent among many DMSHP projects in particular.

- Supply air stream
- GSHP supply and return water pipe surface temperature
- Spot combustion efficiency measurement of pre-existing/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 12-18 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.

### 3.6.3 Intensive Rigor

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, 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:

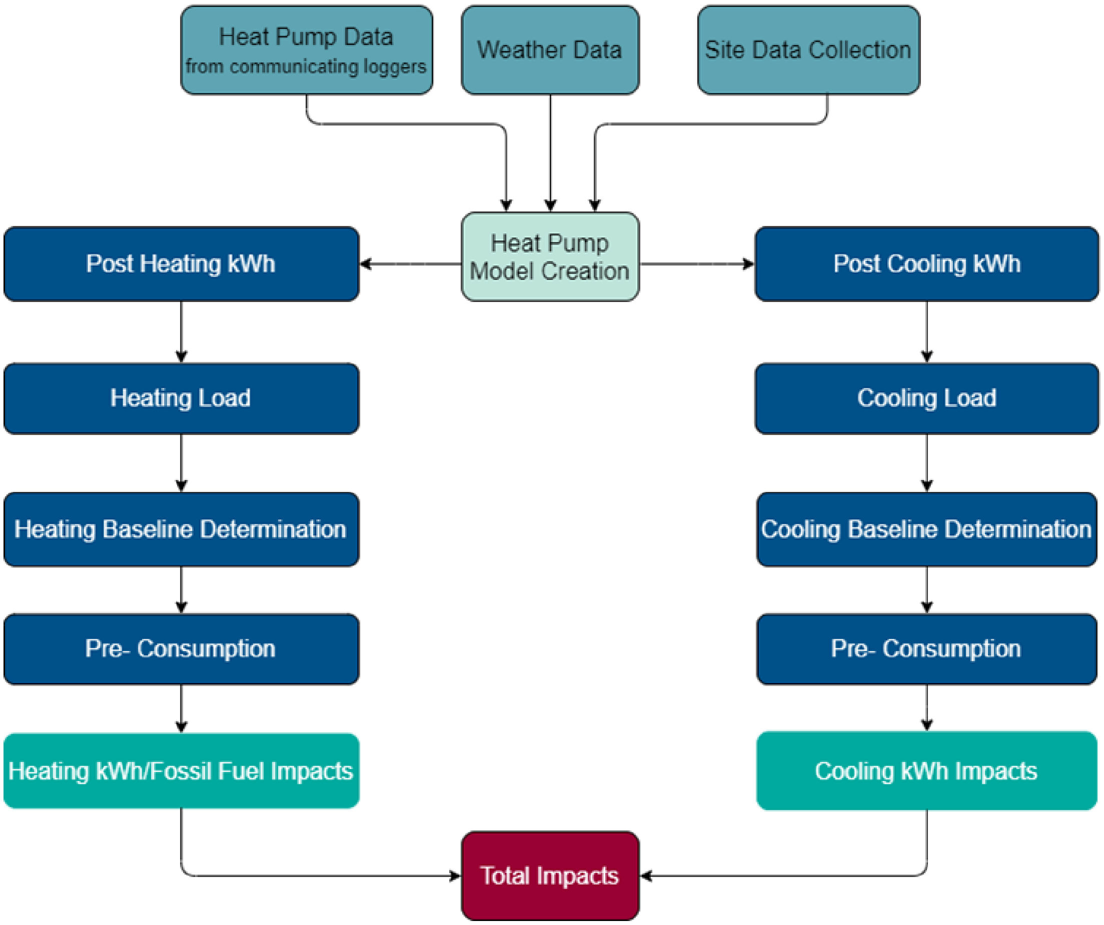
- Spot measurements of airflow
- Anemometer with spot amperage readings of fan circuit for correlations made at various speeds
- For ductless systems, a balometer/flow hood with spot amperage readings
- Long-term true RMS power metering: voltage, amperage, real power, power factor
- Intended to collect 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. After at least 12 months of performance monitoring and data transmission, the evaluation team collected all deployed metering devices, with final retrievals occurring in February 2022.

## 3.7 Phase 2 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 3-3 illustrates the overall analysis approach.

**Figure 3-4. Phase 2 impact analysis flowchart**




## 3.7.1 Installed Condition

DNV's metering approach captures the operation and performance of the installed heat pump system components. The evaluation analysts processed metered interval data to characterize the heat pump's heating/cooling output 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[27] 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.

[27] 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. Evaluators used facility ZIP code to map to the most proximate weather station. In some cases, the climate zone (see Figure 3-1) as defined by closest weather station (via ZIP) differed from the climate zone designation as defined by county. Evaluators believe these differences to be negligible.

### 3.7.2 Baseline Condition

The evaluation analysts considered different data sources to establish the most appropriate, site-specific HVAC baselines, as follows. In general, to establish baseline energy consumption, evaluators presumed that the heating and cooling loads satisfied by rebated heat pumps are equal to the heating and cooling loads that presumably would have been satisfied by the baseline systems.

1. Pre-existing system condition – Evaluators first considered the age and operating condition of the pre-existing heating and cooling systems 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[28].
    b. Normal replacement – If the pre-existing 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 or cooling 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 or cooling baseline for first-year savings considering condition #3.
2. Pre-existing system operation, if applicable – If portions of the facility were still heated or cooled by pre-existing 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. In-person interviews also included questions on what the customer would have chosen for heating and cooling systems absent the influence of the program. Per recent New York TRM guidance, customer perspectives on alternative heating decisions should be considered in the selection of appropriate site-specific baseline.[29]

### 3.7.3 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. After the 2021 cooling season, evaluators retrieved such loggers to conduct similar analysis during the cooling period. Intensive metered data included 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 or cooling 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 4.5.1.2) 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-

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

[29] The TRM version active during the evaluation timeframe, Version 5.2, specified prescriptive baseline systems and efficiencies without consideration of feasibility or customer preferences. Evaluators adopted guidance from more recent TRM versions (Version 8 in 2021, Version 9 in 2022) that incorporate customer preferences (absent program influence) in establishing the appropriate baseline for normal replacement or new construction/expansion installations. For 15% of ASHP systems sampled for M&V, customers indicated they would have installed a HP regardless of the influence of the program. Due to complexities in establishing program influence, which extends beyond the rebate and may include factors such as a more developed contractor base and a more mature supply chain, evaluators calculated gross impacts for such projects by considering each site’s most reasonable, code-compliant fossil fuel-fired system as baseline.

rated heating seasonal performance factor (HSPF[30]) or seasonal energy efficiency ratio (SEER) at the appropriate design condition.

The evaluation team quantified annual energy impact for each metered heat pump system by comparing the heating and cooling 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.

## 3.8 Expansion of Results

At the conclusion of both Phase 1 and Phase 2, 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:

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.

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

# 4 RESULTS

This section presents the results of surveys, interviews, billing analysis, and M&V data analysis. The section concludes with a comparison of Phase 1 and Phase 2 results and an examination of opportunities to refine the heat pump savings assumptions in the New York TRM.

## 4.1 Surveys and Interviews

This section summarizes key findings from customer surveys and installer interviews. Appendix D includes additional results from surveys and interviews.

### 4.1.1 Customer Surveys

DNV surveyed all participating customers and received responses from 775 participants. The customer survey, a copy of which is included in Appendix B, focused on heat pump usage patterns and the characteristics of facilities that received the rebated equipment.

#### 4.1.1.1 Heating Characteristics

Table 4-1 shows the portion of customers using their heat pump for heating and/or cooling. Over three-quarters of respondents indicated their heat pumps are used 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).

**Table 4-1. Seasonal usage patterns via survey (n = 775) extrapolated to population (N = 4,515)**

| 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%** |

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. As shown in Table 4-2, 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 show a diverse set of fuel impacts, including the potential for electric load building.

**Table 4-2. Previous heating system used to serve space for customers in existing buildings (n = 541, N = 2,878)**

| 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%** |

Customers 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. As shown in Table 4-3, natural gas was the most common response, covering nearly two-thirds (60%) of these units, followed by heating oil. All other fuels comprised only a combined 10% of fuel sources. Insofar as heat pumps are a clean heating source, the substantial offset of heating oil is significant, although it is a far less frequent baseline than natural gas.

**Table 4-3. Fuel of previous heating source for customers with non-heat pump pre-existing systems (n = 407, N = 1,995)**

| 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%** |

Table 4-4 shows the current usage patterns of pre-existing heating systems by customers who reported having a previous heating system above in Table 4-3. This question was only asked if the rebated heat pump is used to heat an existing space that was previously heated. Overall, 72% of respondents indicated that they are still using their previous system, with about two-thirds of that group reporting frequent use. This high rate of 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 4-4. Current use of pre-existing heating system (n = 528, N = 2,802)**

| Previous Heating 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%** |

#### 4.1.1.2 Cooling Characteristics

The survey asked customers who have installations in existing spaces and are currently using the heat pump for cooling about the primary equipment 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-rebated 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.

As shown in Table 4-5, 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 4-5. Previous cooling system used to serve space before heat pump (n = 561, N = 3,234)**

| 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%** |

As shown in Table 4-6, respondents were asked if the pre-existing system is still being used to provide cooling and how frequently the system is used. Overall, 19% of respondents indicated they are still using their previous system with about two-thirds of that group reporting infrequent use. 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 4-6. Current use of previous cooling system (n = 486, N = 2,855)

| 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%** |

The survey also explored the impact of operation or maintenance issues on program-rebated heat pumps. Eleven percent of the 775 surveyed customers indicated that their heat pump experienced at least one operational malfunction or unexpected maintenance issue. When probed further, customers categorized the repairs as either mechanical (e.g., fan motors, pressure valves), electrical (e.g., circuit and motherboards, thermostat), piping (e.g., refrigerant[31] or condensate leaks), or due to poor installation (e.g., unlevel installation or improper connections). The frequency of customer-reported repairs was relatively even among the four categories.

#### 4.1.1.3 COVID Behavior Changes

With a heavily residential population of participants, the program's rebated heat pumps experienced changes in use as a result of the COVID-19 pandemic's quarantines and increase in remote work. 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 closer to 40% prior to March 2020. DNV analysts also asked participants what changes (if any) they made to their temperature settings during the heating and cooling seasons. 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. During the heating season, participants who did adjust their temperature setting on average set the temperature 0.1°F warmer. During the cooling season, participants who did adjust their temperature setting set the temperature 0.2°F cooler. These behavior changes led to differences in realized savings during COVID as explored in Section 4.2.2.

### 4.1.2 Installer Interviews

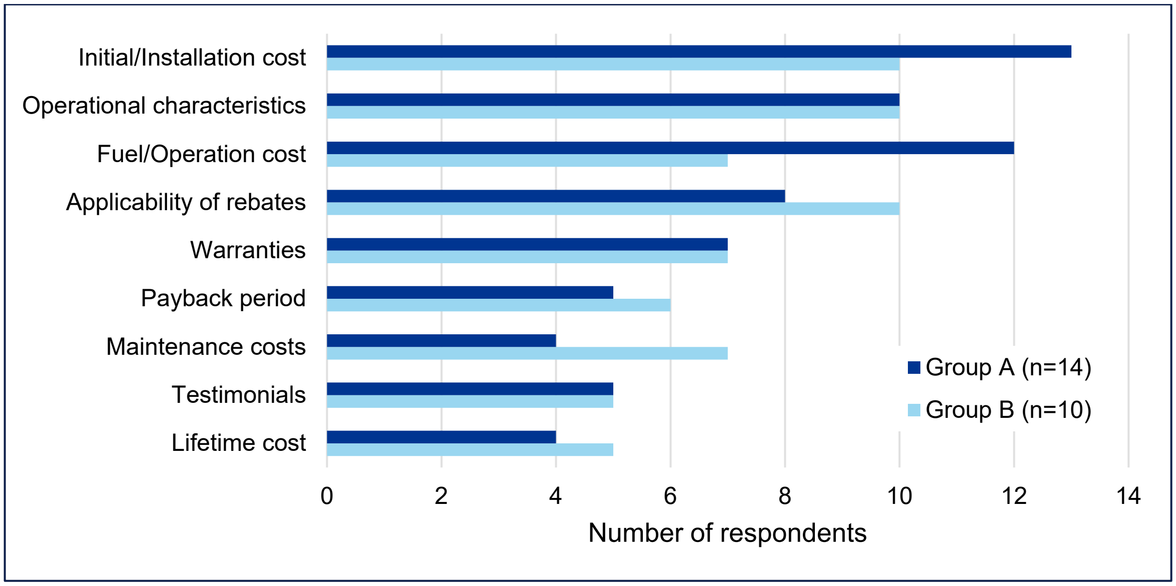
In-depth interviews with participating installers explored the guidance provided by contractors to customers, key factors that influence customer purchasing decisions, and prevalence of advanced control systems. Fifteen of 24 heat pump installers shared their approximate number of annual heat pump installation projects. This number 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.

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 4-1. 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. 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

[31] Regarding refrigerant, installers reported to exclusively sell heat pumps featuring R-410A, which was industry-standard for HVAC equipment during the installation period from program inception through 2018. Evaluators corroborated the installer survey responses by confirming R-410A across all 242 inspected heat pump systems in Phase 2.

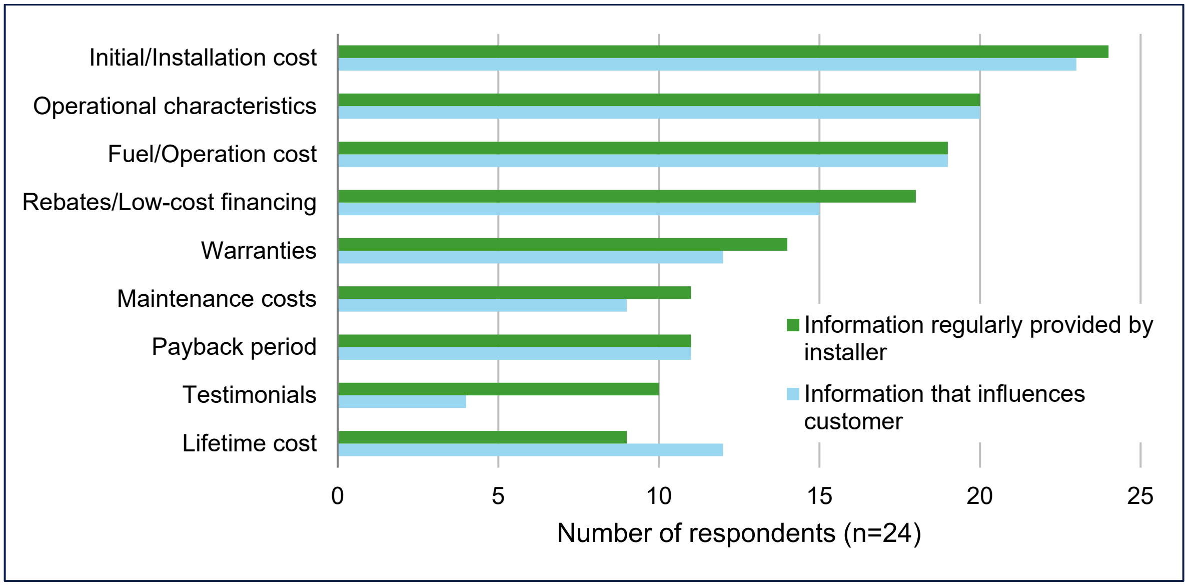
evolving in capability and functionality to meet space conditioning. Both groups of installers provide similar levels of each information type to customers. Nearly all Group B installers (> 5 applications) offer information on fuel, operation, and initial installation costs. Less than half of the installers 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 4-1. Information regularly provided to customers by installers at point of sale**



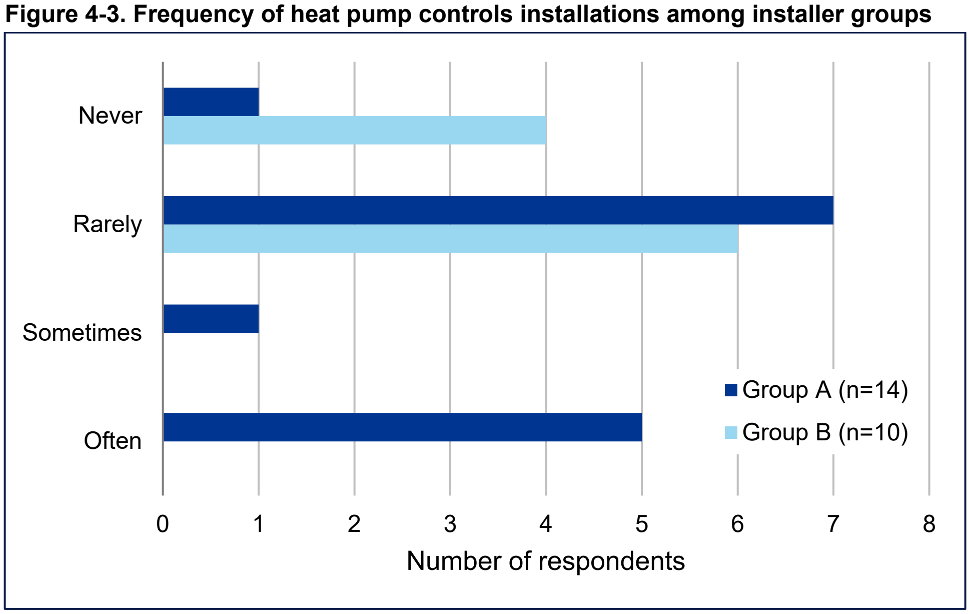

Installers were asked what information influences customers during purchase. Figure 4-2 compares installer responses (based on what they believed influences customer decisions) to the information they actually provided to customers. As would be expected, the three pieces of information most frequently 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 4-2. Information that influences customer decisions at point of sale**




DNV interviewers also asked installers 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. As shown in Figure 4-3, 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 4-3. Frequency of heat pump controls installations among installer groups**




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 occasionally 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.

## 4.2 Phase 1 Billing Analysis Results

This section presents the results of the Phase 1 billing analysis by heat pump type, fuel type, climate zone, building type, and other segments of interest based on customer-reported data collected through the survey. Phase 1 results provided a preliminary look into the performance of NYSERDA's heat pump programs.

### 4.2.1 Comparison of Pre- and Post-Installation Periods

The DNV team first assessed impacts of the rebated heat pumps by comparing weather-normalized consumption data before and after installation and prior to the COVID-19 pandemic. Table 4-7 compares the total site-level energy savings (MMBtu) for both ASHP and GSHP and overall. 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 4-7 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, DNV estimates that the ASHP VGS realization rate is between 16% and 38% (27% ± 11%) with a 90% confidence.

**Table 4-7. Phase 1 billing analysis results (pre-COVID) 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**<br>90 - 191 | 228,373 | **62,024**<br>74,615 - 53,291 | **27%**<br>33% - 23% | **40%**<br>43% - 30% | **11%**<br>14% - 7% |
| GSHP | 470 | **90**<br>80 - 114 | 42,858 | **21,787**<br>20,622 - 18,965 | **51%**<br>48% - 44% | **16%**<br>15% - 14% | **8%**<br>7% - 6% |
| **Statewide** | **4,513** | **217**<br>170 - 305 | **271,231** | **83,811**<br>95,237 - 72,256 | **31%**<br>35% - 27% | **30%**<br>33% - 22% | **9%**<br>12% - 6% |

The next subsections examine results by heat pump type and among segments of interest.

### 4.2.1.1 ASHP Results

Table 4-8 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. A realization rate could not be calculated for some fuels due to zero program-reported savings.

**Table 4-8. Phase 1 ASHP results by fuel (pre-COVID)**

| 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**<br>-1,680,631 - -1,861,358 | **14%**<br>9% - 9% | **61%**<br>153% - 73% | **9%**<br>13% - 7% |
| Natural gas[2] | **MMBtu** | **-** | **0** | **8,067**<br>5,488 - 10,665 | **N/A**<br>- | **N/A**<br>- | **N/A**<br>- |
| Oil | **MMBtu** | **-** | **295,359** | **38,508**<br>39,002 - 32,291 | **13%**<br>13% - 11% | **47%**<br>34% - 39% | **6%**<br>5% - 4% |
| Oil | **Gallons** | **-** | **2,148,063** | **280,055**<br>283,653 – 234,843 | **13%**<br>13% - 11% | **47%**<br>34% - 39% | **6%**<br>5% - 4% |
| Propane[2] | **MMBtu** | **-** | **0** | **23,643**<br>26,223 - 12,207 | **N/A**<br>- | **N/A**<br>- | **N/A**<br>- |
| Propane[2] | **Gallons** | **-** | **0** | **258,961**<br>287,215 – 133,704 | **N/A**<br>- | **N/A**<br>- | **N/A**<br>- |
| All fossil fuels | **MMBtu** | **-** | **295,359** | **71,426**<br>80,348 - 59,641 | **24%**<br>27% - 20% | **37%**<br>41% - 29% | **9%**<br>11% - 6% |
| **Total energy** | **MMBtu** | **127**<br>90 - 191 | **228,373** | **62,024**<br>74,615 - 53,291 | **27%**<br>33% - 23% | **40%**<br>43% - 30% | **11%**<br>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 ASHP use. Evaluators next examined ASHP results by climate zone, as shown in Table 4-9. Downstate installations in climate zone 4 realized markedly lower savings than upstate zones 5 and 6; this finding was further observed and explored in Phase 2.

**Table 4-9. Phase 1 ASHP results by climate zone (pre-COVID)**

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

#### 4.2.1.2 GSHP Results

Table 4-10 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 4-10. Phase 1 GSHP results by fuel type (pre-COVID)**

| 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**<br>-25,091 – -387,136 | **21%**<br>2% - 23% | **155%**<br>2550% - 93% | **32%**<br>39% - 22% |
| Natural gas | **MMBtu** | **-** | **8,053** | **15,310**<br>14,585 - 13,429 | **190%**<br>181% - 167% | **77%**<br>76% - 74% | **146%**<br>138% - 123% |
| Oil | **MMBtu** | **-** | **33,252** | **12,742**<br>10,850 - 11,058 | **38%**<br>33% - 33% | **27%**<br>32% - 24% | **10%**<br>11% - 8% |
| Oil | **Gallons** | **-** | **241,830** | **92,669**<br>78,913 – 80,422 | **38%**<br>33% - 33% | **27%**<br>32% - 24% | **10%**<br>11% - 8% |
| Propane | **MMBtu** | **-** | **7,181** | **3,257**<br>2,889 - 2,921 | **45%**<br>40% - 41% | **48%**<br>48% - 43% | **22%**<br>19% - 18% |
| Propane | **Gallons** | **-** | **78,655** | **35,676**<br>31,639 – 31,999 | **45%**<br>40% - 41% | **48%**<br>48% - 43% | **22%**<br>19% - 18% |
| All fossil fuels | **MMBtu** | **-** | **48,485** | **22,800**<br>20,634 – 19,969 | **47%**<br>43% - 41% | **47%**<br>43% - 41% | **19%**<br>21% - 17% |
| **Total energy** | **MMBtu** | **108**<br>96 - 134 | **42,858** | **21,787**<br>20,622 - 18,965 | **51%**<br>48% - 44% | **16%**<br>15% - 14% | **8%**<br>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 3.5.2. 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.

Table 4-11 presents GSHP results by climate zone. There were no zone 4 installations in the analysis sample. 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 was further investigated in Phase 2.

**Table 4-11. 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**<br>0 - 0 | **-**<br>- | **-**<br>- | **-**<br>- |
| 5 | **64**<br>58 - 80 | **102**<br>102 – 102 | **46**<br>48 - 42 | **45%**<br>47% - 41% |
| 6 | **26**<br>22 - 34 | **94**<br>97 - 88 | **61**<br>48 - 46 | **65%**<br>50% - 53% |

### 4.2.1.3 Results by Segment

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.

Baseline plays an important role in calculating savings for heat pumps. Table 4-12 presents the savings results for the different customer-reported baseline scenarios. New construction installations, which invoke a code-compliant baseline reflective of the alternative system most preferred by the customer, realized lower savings than displacements of existing operable equipment.

**Table 4-12. Phase 1 combined (ASHP and GSHP) per-site savings by space type (pre-COVID)**

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

Table 4-13 presents the savings results based on customer-reported heat pump operating season.

**Table 4-13. Phase 1 combined per-site savings by operating season (pre-COVID)**

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

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. However, despite the year-round use, HPs realized slightly over a third of reported MMBtu savings. Table 4-14 illustrates one of the primary reasons for low realization rates—load-sharing with pre-existing systems.

**Table 4-14. Phase 1 combined per-site savings by frequency of pre-existing heating system use (pre-COVID)**

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

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.

### 4.2.2 COVID Impacts

This section presents differences in realized HP impacts as a result of participant behavior changes during the COVID-19 pandemic.

The energy usage calculated during the COVID period beginning March 2020 was compared to energy usage calculated during the pre-COVID period reviewed in the prior sections. Note that the pre-COVID period refers to the 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 4-15 shows the total per-site energy usage values before and amid COVID and disaggregates the impact on energy usage by electric only and electric and fossil fuel sites. The range of results is due to the different analysis techniques applied to each site depending on the filtering criteria, as discussed in Section 3.5.2.

**Table 4-15. Impact of COVID on total per-site energy usage**

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

The main drivers for the increased energy usage across sites were increases in heating load (11% or 4.9 MMBtu/yr per site) and base load (5% or 1.9MMBtu/yr per site). The cooling load across sites during COVID decreased by 12% or 0.3 MMBtu/yr per site. The base load increase correlates with the survey responses indicating that residents stayed at home for 3 hours more per day during weekdays and 1 hour more during weekends amid COVID. Increased occupied hours correspond to more lighting and plug loads which contribute to the increased base load. Increased heating load correlates with increased occupancy hours and raised heating setpoints as indicated by 20% of surveyed customers. The decrease in cooling load during the COVID period is unexpected. The magnitude of the cooling load (2.3 MMBtu/yr per site pre-COVID and 2.0 MMBtu/yr per site during COVID) is small, and accounts for 2% to 3% of the total energy usage. Thus, the decrease in cooling load is an even smaller fraction of the total energy usage which may be difficult to accurately detect through monthly billing analysis, especially when only four or five months of the year typically require cooling.

## 4.3 Phase 2 M&V Results

This section presents the evaluated impact results of Phase 2 M&V. Table 4-16 compares program-reported and evaluated site energy savings (MMBtu) for both ASHP and GSHP, as well as statewide. These results incorporate all fuels observed among the 137 sampled projects, including electric, natural gas, oil, propane, wood, and coal.

**Table 4-16. Phase 2 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 | 87,447 | 38%† | ±30% | ±12% |
| GSHP | 470 | 36 | 44,173 | 42,862 | 97% | ±16% | ±15% |
| **Statewide** | **4,515** | **122** | **272,546** | **130,309** | **48%** | **±21%** | **±11%** |

* The completed count is lower than the total sample of 137 due to exclusion of 7 sites with anomalous on misrepresentative data and 8 Pilot Program sites for which NYSERDA did not claim savings.

† For 15% of ASHP systems sampled for M&V, customers indicated they would have installed a HP regardless of the influence of the program. Due to complexities in establishing and discounting program influence, which extends beyond the rebate and may include factors such as a more developed contractor base and a more mature supply chain, evaluators calculated gross impacts for such projects by considering each site's most reasonable, code-compliant fossil fuel-fired system as baseline. Evaluators estimate that this baseline treatment increased the ASHP RR by 6%.

In the next sections, we explore the makeup of the evaluated savings by season, by fuel source, and by climate zone. Section 4.4 compares evaluation results between Phase 1 and Phase 2. Section 4.5 examines Phase 2 results in the context of the New York TRM's savings algorithms and assumptions for heat pump measures. Each of the forthcoming sections provides insights on why Phase 2 VGS impacts differed from program-reported impacts.

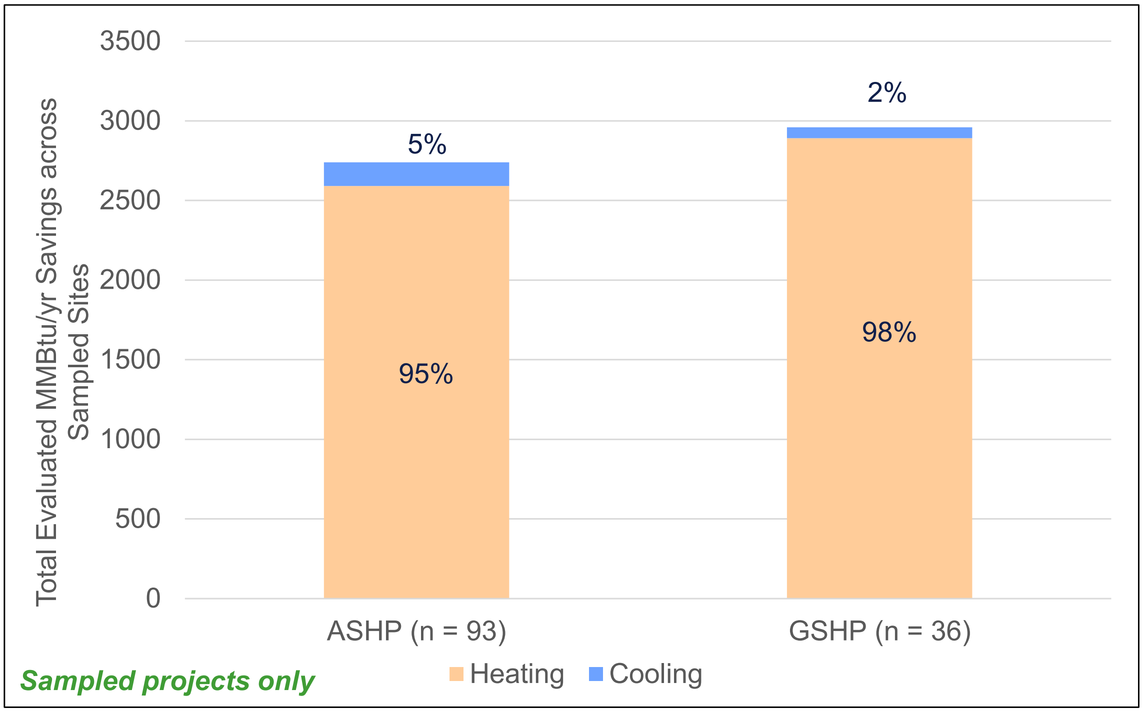
### 4.3.1 Phase 2 Savings by Season

Figure 4-4 presents the makeup of evaluated savings by season for both ASHP and GSHP technologies. The figure illustrates that heating impacts comprise a significant majority of annual MMBtu savings for both system types. Heating impacts outpace cooling impacts for two primary reasons:

1. Heat pump installations produce significantly more MMBtu savings when compared with non-heat pump heating systems, such as electric resistance or fossil fuel-fired boilers or furnaces. As discussed in Section 4.5.1.2, HP heating performance exceeds that of traditional heating systems by a factor of three or more. On the other hand, HP cooling performance is incrementally better than alternative cooling systems such as window or central A/Cs.
2. New York's climate zones correspond to significantly more heating degree days per year (6,438 for Albany) than cooling degree days (550) in a typical meteorological year.[32]

[32] NYSERDA, "Monthly Cooling and Heating Degree Day Data," last updated February 2022. https://www.nyserda.ny.gov/about/publications/ea-reports-and-studies/weather-data/monthly-cooling-and-heating-degree-day-data#Albany

**Figure 4-4. Phase 2 evaluated savings by season by heat pump technology**




Evaluators are limited in comparing evaluated savings with reported savings by season. The programs did not claim cooling savings for ASHP installations; therefore, evaluators cannot develop cooling-only RRs for ASHPs. Section 4.3.2.2 examines aggregate heating and cooling season impacts for GSHPs.

## 4.3.2 Phase 2 Impacts by Fuel

Table 4-17 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 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 4-17. Realization rates and relative precisions (90% confidence) by fuel and by heat pump technology**

| | | Electric | | Natural Gas | | #2 and #6 Fuel Oils | | Propane | | All Fossil Fuels | | Total MMBtu | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | n | RR | RP | RR | RP | RR | RP | RR | RP | RR | RP | RR | RP |
| ASHP | 86 | 0.20 | 59% | N/A | N/A | 0.05 | 44% | N/A | N/A | 0.31 | 33% | 0.38 | 30% |
| GSHP | 36 | 0.79 | 141% | 1.52 | 55% | 0.20 | 38% | 2.63 | 38% | 0.77 | 25% | 0.97 | 16% |
| **Statewide** | 122 | 0.25 | 59% | 10.25 | 148% | 0.07 | 31% | 3.61 | 35% | 0.39 | 25% | 0.48 | 21% |

ASHP projects realized 20% of electric impacts[33], 31% of fossil fuel impacts, and 38% of overall MMBtu impacts. As explored throughout the remainder of this section, the primary reason for low ASHP RRs is lower-than-expected heating output from the installed systems, of which over 99% in the evaluation population are DMSHPs.

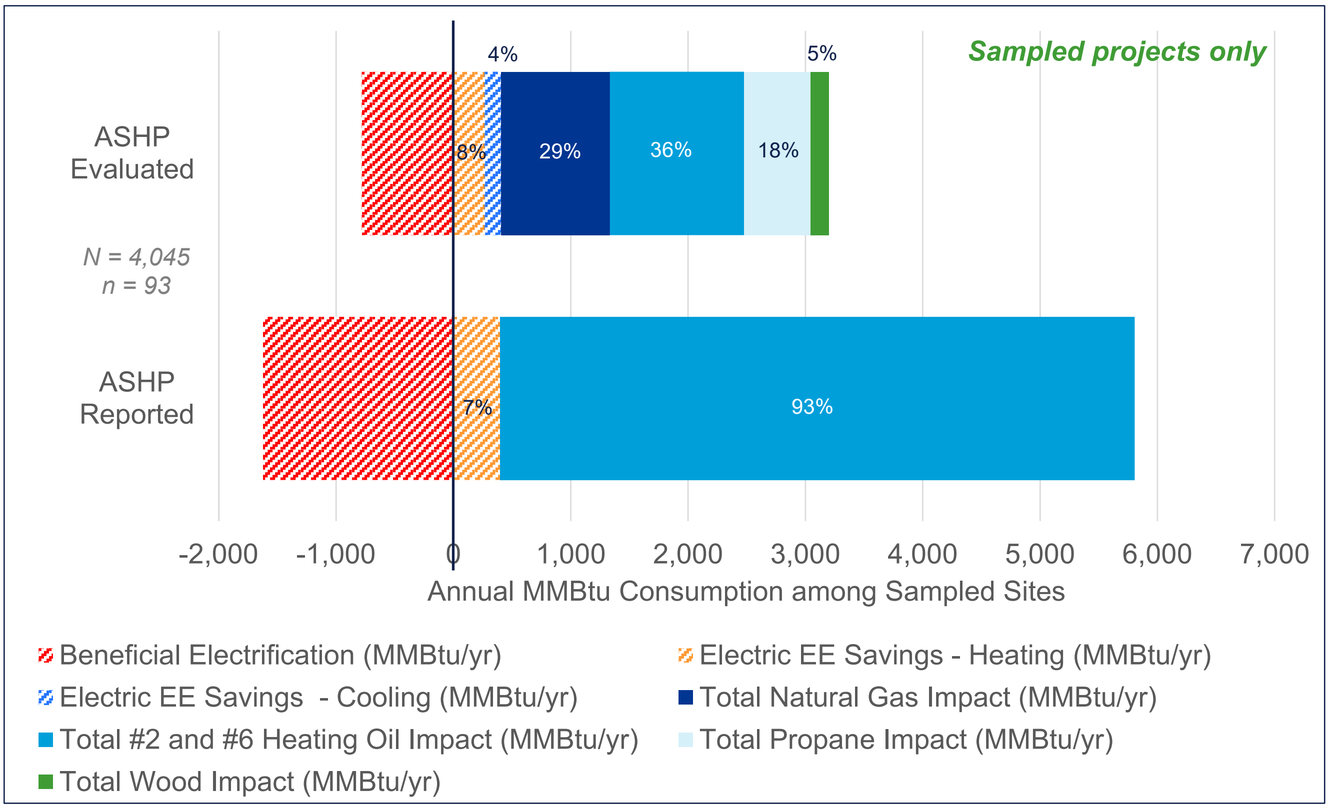
GSHP projects realized 79% of electric impacts, 77% of fossil fuel impacts, and 97% of overall MMBtu impacts. The primary contributors for the GSHP RRs are lower-than-expected heating output, better-than-expected operating efficiency, and more favorable baseline conditions leading to slightly higher evaluated impacts.

### 4.3.2.1 ASHP Results by Fuel

Figure 4-5 illustrates the impacts by fuel for ASHP installations. The figure presents evaluated and reported site MMBtu impacts by fuel, with beneficial electrification (added electric load) illustrated as the leftmost striped bar. MMBtu savings are illustrated by the striped orange (electric energy efficiency savings during heating operation), striped blue (electric savings during cooling operation), and solid bars (various displaced fossil fuels).

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. Figure 4-5 presents impacts among the sample of 86 ASHP projects included in the 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 4-5. Phase 2 reported vs. evaluated ASHP impacts by fuel**




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 (29%), fuel oils (36%), propane (18%), and wood (5%).

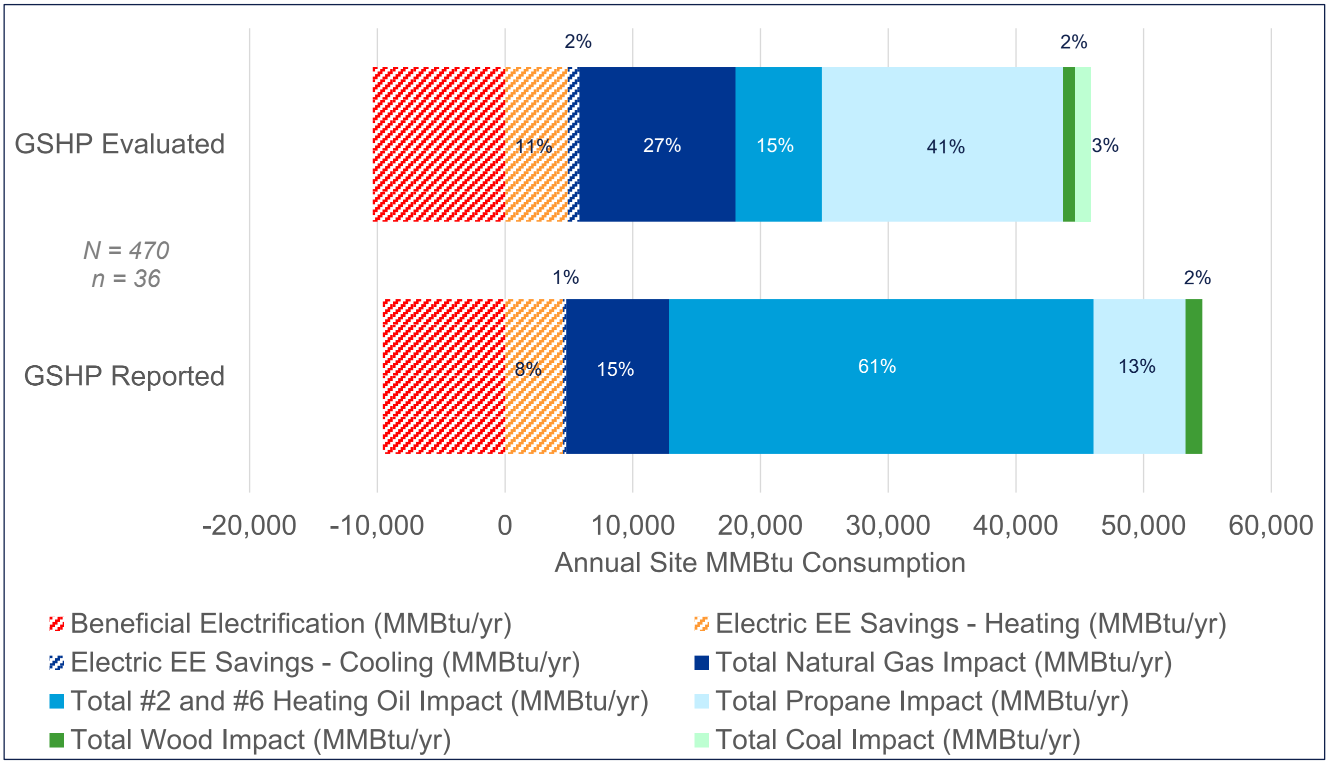
[33] For both ASHP and GSHP systems, the reported and evaluated electric impacts are negative due to the beneficial electrification of the rebated installations. For example, ASHPs resulted in an electric "penalty" 92% lower than predicted by the programs.

## 4.3.2.2 GSHP Results by Fuel

Additionally, electric resistance-to-HP installations accounted for 8% 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. While the program did not claim cooling season impacts, evaluators determined slight relative savings (4%) from cooling season operation as compared with the site-specific baseline.

Figure 4-6 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 4-6. Phase 2 evaluated vs. reported GSHP impacts by fuel**




Evaluators determined different GSHP fuel savings shares than assumed by the programs. Natural gas accounted for 27% of evaluated MMBtu savings, as compared with the program's assumption of 15%. On the other hand, oil accounted for 15% of evaluated MMBtu savings but 61% of the program's savings claim. Evaluators also determined that coal was the primary pre-existing heating fuel for one of the projects in the sample.

For each GSHP installation, the programs assumed the building's cooling load equaled 24% of the Manual J heating load. However, the programs did not distinguish between heating and cooling savings claims in tracking databases, only claiming total electric impacts. Evaluators reviewed the program's GSHP savings calculator and back-calculated electric cooling and heating impacts for each GSHP installation. Figure 4-6 compares such "presumed reported" impacts with evaluated electric impacts by season for GSHP projects. The figure illustrates that evaluators determined more than twice the cooling savings as presumably claimed by the program, though they constitute a small share of overall impacts.

### 4.3.3 Phase 2 Impacts by Climate

Figure 4-6 illustrates ASHP performance by climate zone, labeled using 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 found that downstate installations displaced preexisting heating systems less frequently than upstate installations—i.e., downstate customers were more likely to retain and use their preexisting heating source.

**Figure 4-7. Phase 2 ASHP results by climate zone**

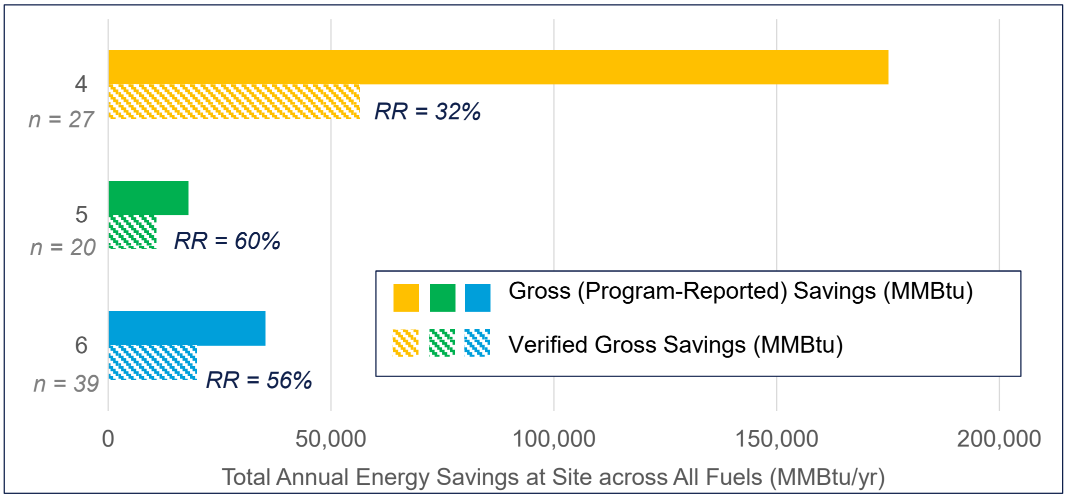
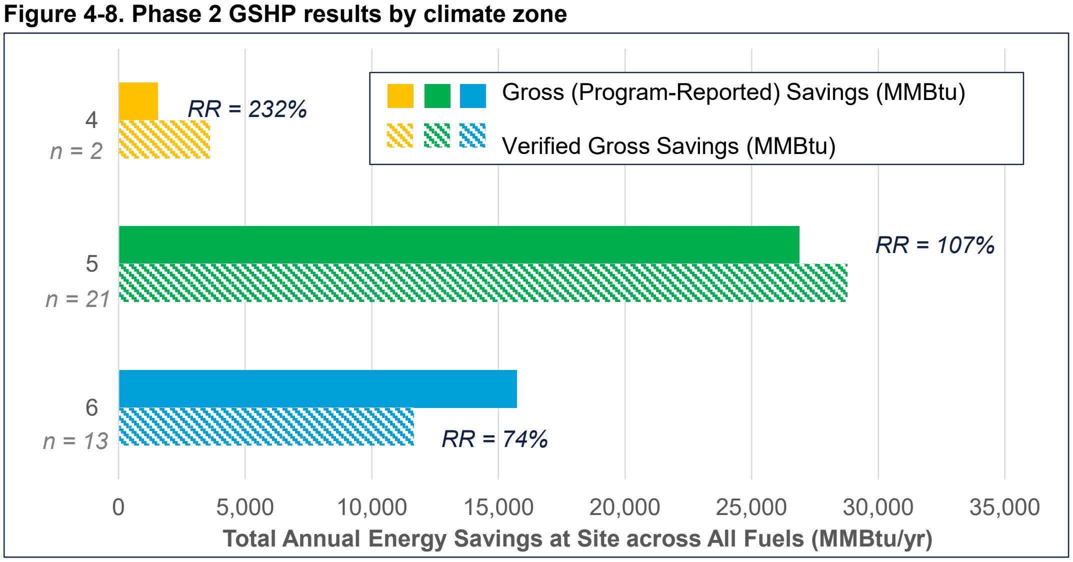



Figure 4-8 compares the performance of GSHP projects by climate zone, illustrating varying performance between upstate climate zones 5 and 6. Evaluators do not presume these differences to be climate-related; rather, the differences likely occur due to variation in project characteristics such as baseline. Climate zone 4 only featured two projects in the sample.

**Figure 4-8. Phase 2 GSHP results by climate zone**




### 4.3.4 Additional Results by Segment

This section examines results by additional segments of interest, including system type, customer type, and use of legacy heating systems.

Evaluators compared the performance of ducted ASHPs and DMSHPs, as shown in Table 4-18. While evaluators attempted to include as many ducted ASHP projects in the evaluation as possible, only 3 of the 12 ducted ASHPs in the population were evaluated. Ducted systems realized, on average, about 80% more claimed MMBtu savings per project than DMSHPs, though low sample size should be considered.

**Table 4-18. Phase 2 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 | 339 | 1.14 | ±17% | ±19% |
| ASHP Ductless | 4,033 | 83 | 227,996 | 82,341 | 0.36 | ±31% | ±11% |
| **Total ASHP** | **4,045** | **86** | **228,373** | **87,447*** | **0.38** | **±30%** | **±12%** |

* The total does not match the sum of rows due to differences in statistical weighting.

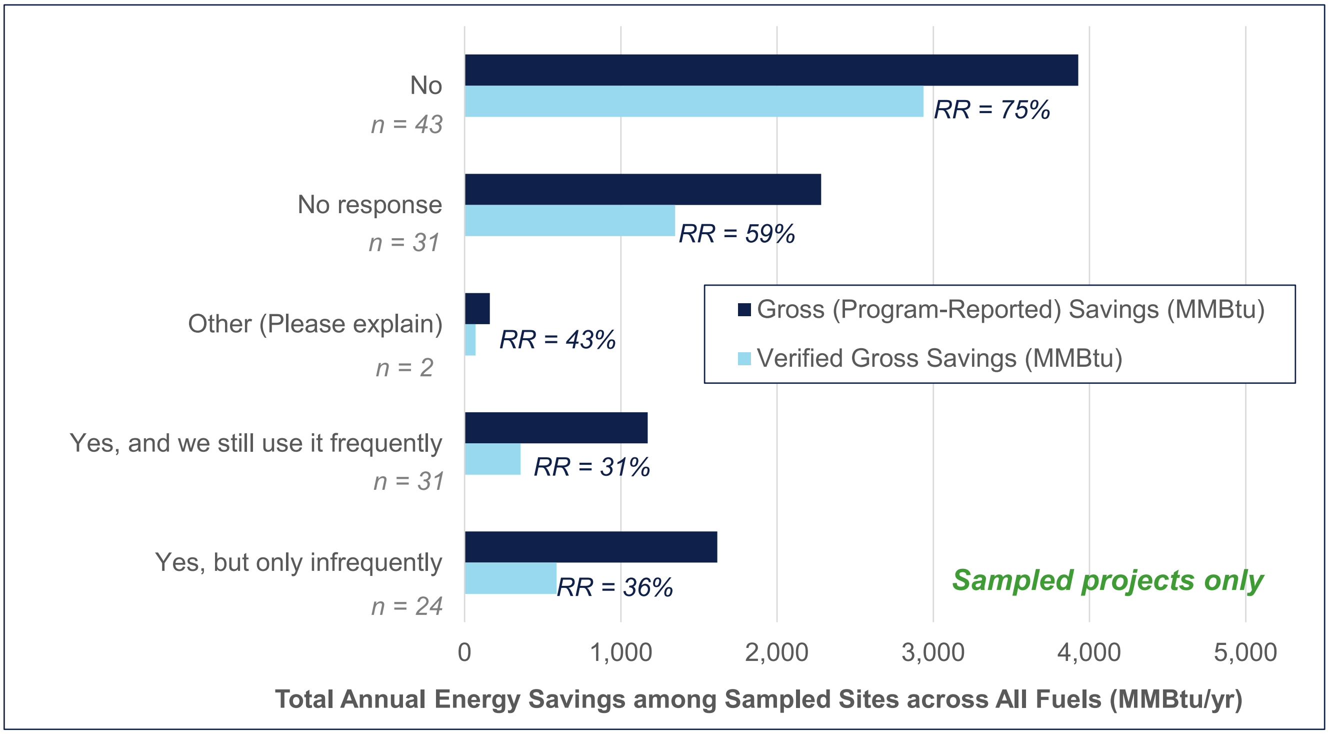
Table 4-19 compares the performance of GSHP projects between commercial and residential sectors, as classified in program tracking data and confirmed during site visits. We found similar performance between sectors and overall, though low sample size is a consideration for the commercial sector.

**Table 4-19. Phase 2 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 | 4,331 | 0.95 | ±23% | ±22% |
| Single-Family Residential | 447 | 31 | 37,533 | 36,741 | 0.98 | ±22% | ±21% |
| **Total GSHP** | **466** | **36** | **42,073** | **40,825** | **0.97** | **±16%** | **±15%** |

Section 4.1.1.1 examines participant survey responses regarding usage of preexisting heating systems. Overall, 55% of survey respondents reported using the legacy systems after heat pump installation. Figure 4-9 examines the effects of preexisting heating system use on evaluated impacts. As expected, customers who do not use preexisting heating systems significantly outperform those that do. Frequency of legacy system use did not significantly affect the evaluated savings.

**Figure 4-9. Statewide Phase 2 results by customer survey response on pre-existing heating system use**




## 4.4 Comparison of Evaluation Phases

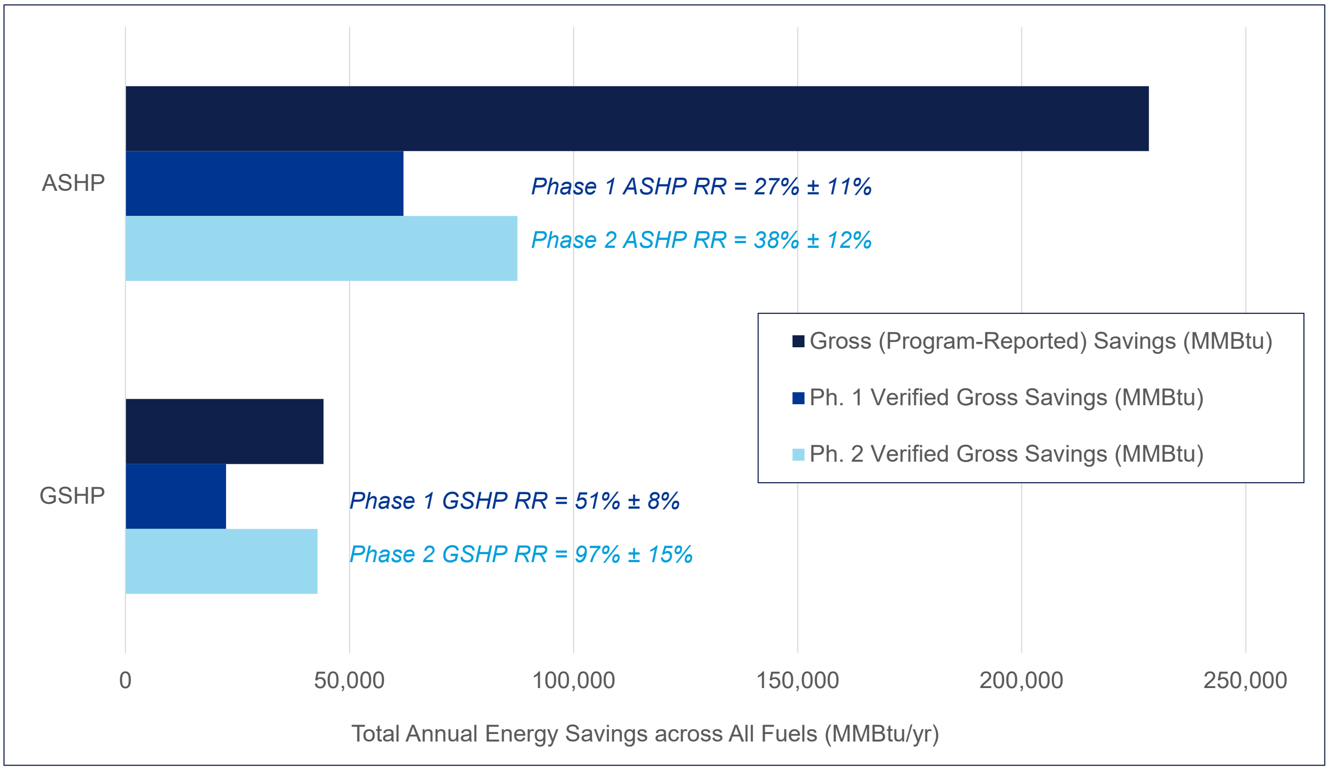
Figure 4-9 illustrates the comparison of total MMBtu impacts between Phase 1 premise-level utility consumption data-based analysis and Phase 2 equipment-level M&V. Evaluated ASHP MMBtu impacts increased by 11% from Phase 1 to Phase 2; this difference is primarily attributable to Phase 2's baseline treatment that more frequently defaulted to fossil fuel alternatives. Aligning the baseline treatment between the two phases would have reduced the Phase 2 MMBtu RR to 32%, indicating reasonable prediction from premise-level analysis.

However, M&V assessment of GSHP projects led to 44% more MMBtu impacts than premise-level consumption analysis. Evaluators attribute this difference to two primary reasons:

- GSHP projects are typically more complex and therefore more likely to involve nuanced baselines that are most accurately characterized through on-site M&V (as done in Phase 2) than a web-based customer survey (Phase 1). Due to time constraints, the web-based survey focused on characterizing preexisting system type, fuel, and frequency of current use; the survey did not assess preexisting system operability, likelihood of retention, or preferred alternatives absent the program. To be consistent with program savings estimation, evaluators presumed normal replacement or new construction GSHP projects to warrant a code-compliant ASHP baseline. However, through on-site data collection and in-depth interviews, evaluators investigated the customers' preferred alternative heating and cooling systems. If reasonable and feasible given site-specific constraints (e.g., natural gas connectivity), these alternatives constituted the code-compliant baseline for end-of-life or new construction projects. 14 GSHP systems in the Phase 2 sample resulted in fossil fuel-fired normal replacement baselines, which led to significantly higher efficiency gains as compared with code-compliant ASHP baselines.

- Only 11 GSHP projects were assessed in both Phase 1 and Phase 2. Billing analysis attrition, difficulties in recruiting, and a relatively small GSHP recruitment pool limited the evaluators' ability to assess identical sites in both phases of study. The billing analysis pool included 72 more GSHP projects than the M&V sample.

**Figure 4-10. Comparison of Evaluation Phase 1 and Phase 2 results by heat pump technology**




## 4.5 TRM Insights

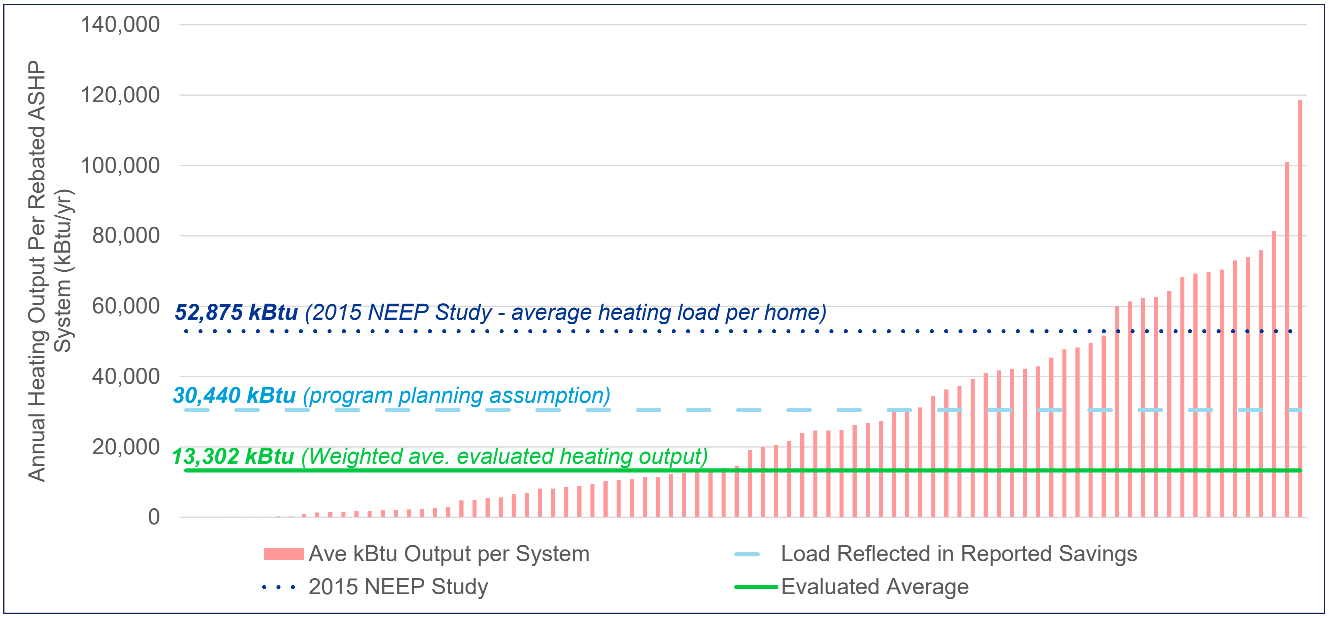
As part of Phase 2, evaluators examined system-level metered data more closely to quantify relevant operating parameters such as heating and cooling loads, full-load hours, and coefficients of performance (COPs) for both ASHP and GSHP systems. This analysis helps reveal why rebated HP systems underperformed overall compared to expectations. When possible, evaluators have contextualized the results to be relevant for the HP algorithms included in the current New York TRM. Additional results are presented in Appendix J.

### 4.5.1 ASHP Parameters

#### 4.5.1.1 Heating and Cooling Outputs

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 4-10. Program-reported savings are based on a 2015 NEEP study that estimated whole-home heating consumption for single-family residences with oil heating. 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 were identical for all ASHPs, whether ducted or ductless, and claimed 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. In the context of the current New York TRM savings algorithm, **installed ASHPs, on average, corresponded to a 0.3 sizing factor** that accounts for partial heating displacement.

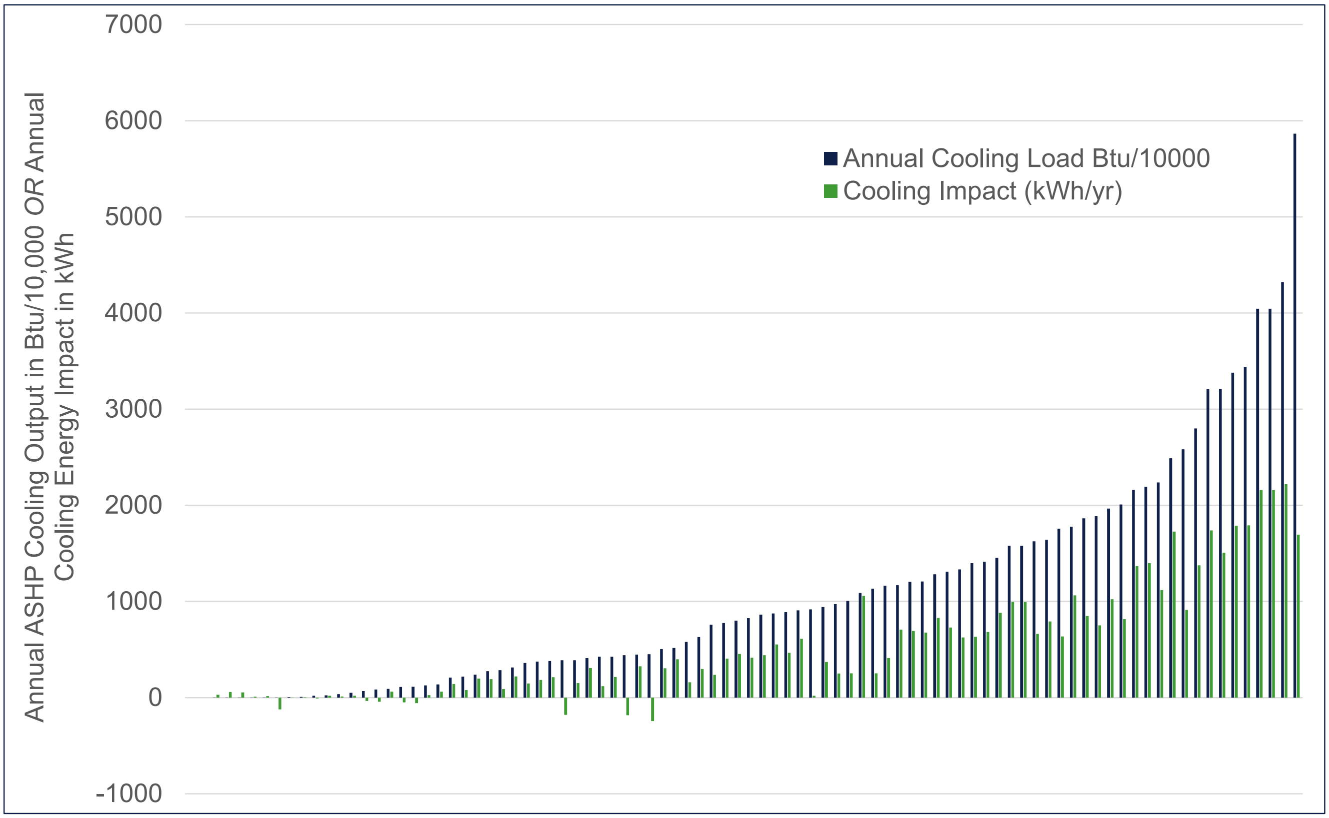
**Figure 4-11. Program-assumed vs. evaluated ASHP annual heating loads**




Evaluators primarily attribute the 38% 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. By pairing the metered operation with rated capacities by ASHP system, evaluators determined **565 annual equivalent full-load heating hours**. As a point of comparison, NY TRM Version 9 recommends a range of EFLHH from 786 to 1,125 for whole-home heating systems depending on region and vintage.

Evaluators determined a broad range of **annual cooling outputs that generally led to electric savings** when compared to site-specific baselines. The programs' ASHP deemed savings value presumed zero cooling impacts. Figure 4-11 illustrates each sampled ASHP site's annual cooling outputs in increasing order (in Btu/10,000 for scale), along with each site's cooling impact in kWh. Nine projects resulted in a cooling penalty (i.e., new electric load), as the customer indicated they would not have used mechanical cooling if not for participating in the program. As illustrated by relatively low blue bars corresponding with negative impacts, these customers infrequently used the installed heat pumps for cooling. The remaining 84 ASHP projects resulted in cooling savings that significantly outweighed the small penalties illustrated in the figure. Ten ASHP projects produced zero or near-zero cooling output. Overall, when compared with rated cooling capacities, **ASHPs provided cooling over 434 annual equivalent full-load cooling hours**.

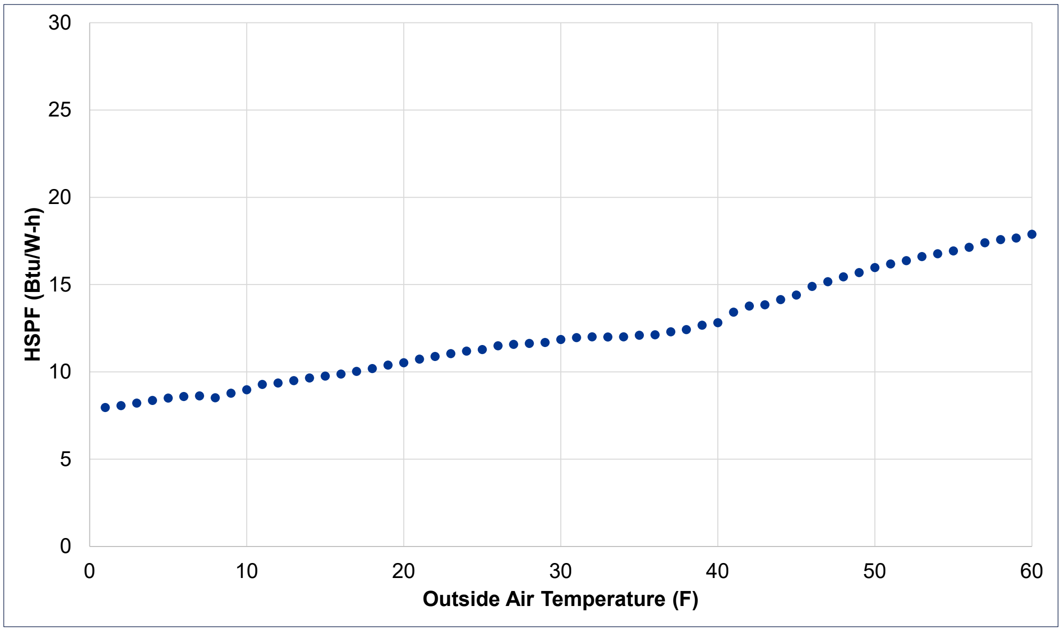
Figure 4-12. Annual cooling output of sampled ASHP projects vs. annual cooling impacts in kWh




### 4.5.1.2 Performance

Evaluators next examined the performance of rebated ASHPs through intensive metering of 8 projects. We found that rebated **ASHPs generally operate near rated heating 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 4-13.

**Figure 4-13. Example ASHP heating performance vs. outside air temperature curve**




Evaluators determined that the rebated ASHPs achieved an overall, weighted-average HSPF[34] 3% lower than the weighted-average rated HSPF, as shown in Table 4-20. Both rated and achieved HSPFs are significantly higher than the 8.5 HSPF reflected within the program-assumed heating load shown in Table 4-10.

**Table 4-20. Evaluated vs. program-assumed HSPF and SEER for ASHPs**

| ASHP Efficiency Metric | Weighted Average Values: Program-Assumed | Weighted Average Values: Rated | Weighted Average Values: Evaluated |
|---|---|---|---|
| HSPF (Heating) | 8.53 | 11.65 | 11.34 |
| SEER (Cooling) | N/A | 22.97 | 21.62 |

The evaluated HSPF of 11.3 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 4-11, the ASHPs operate less—and have fewer opportunities for heating savings—than assumed by the programs.

Evaluators also examined cooling performance in the form of seasonal energy efficiency ratio (SEER). Contrary to heating, cooling performance degrades as temperature increases. Evaluators determined an overall, weighted-average SEER of 21.62 as compared with the weighted-average SEER of 22.97 per manufacturer ratings. Rebated ASHPs generally provided cooling at temperatures warmer than rated conditions, resulting in a 6% decrease in efficiency as compared with rated. The programs did not claim cooling impacts from ASHP installations.

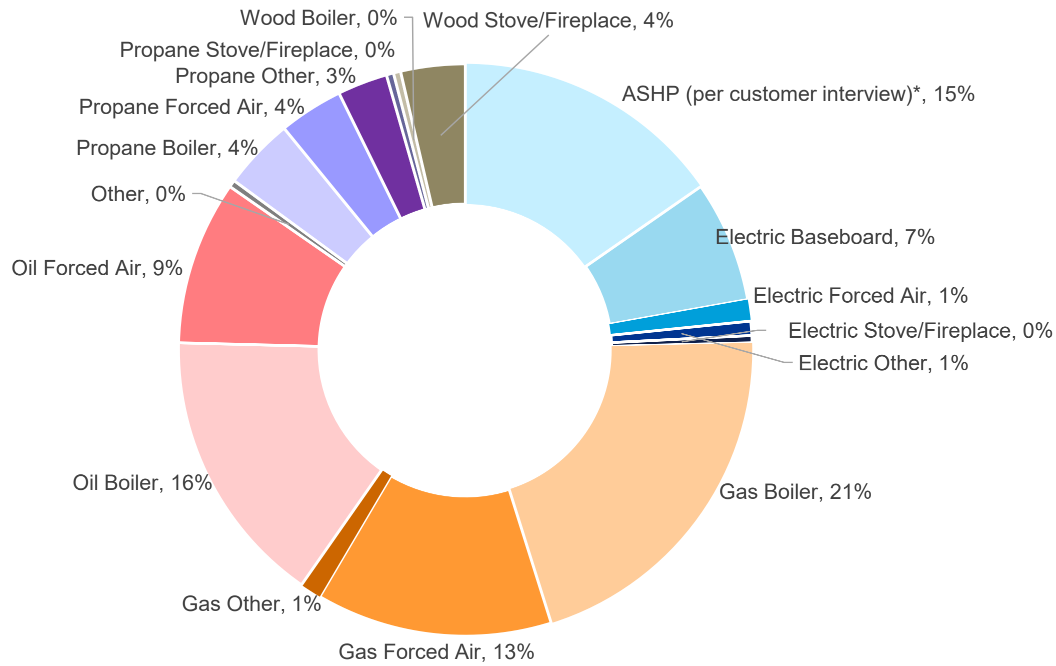
### 4.5.1.3 Baselines

Another notable contributor to the ASHP MMBtu RR is baseline. As described above, the programs assumed that all rebated ASHPs replace a blend of oil-fired heating systems (with an assumed coefficient of performance[35] of 0.75) and electric-

[34] System-specific HSPFs were averaged together using weights defined by rated heating capacities.
[35] COP is converted to HSPF through multiplication with a conversion factor of 3.412 Btu/Watt.

resistance heating systems (COP = 1). Figure 4-14 illustrates the evaluators' heating baseline characterization of 193 ASHP systems installed in 93 sampled projects.

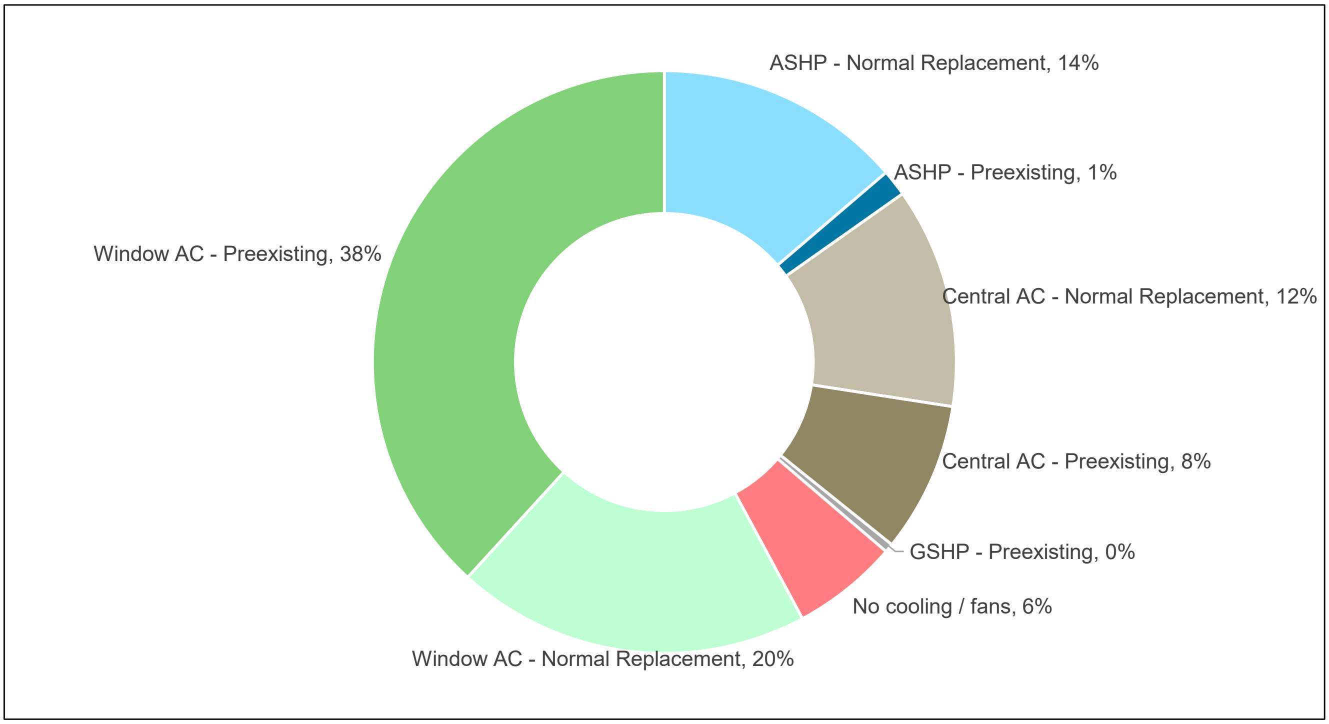
**Figure 4-14. Heating baseline characterization of ASHP systems in Phase 2 sample**




* For 15% of sampled ASHP systems, customers indicated they would have installed a HP regardless of program intervention. Due to complexities with establishing the influence of the programs on accelerating the heat pump market in New York, evaluators calculated gross impacts for such projects by considering the most reasonable, code-compliant fossil fuel-fired system as baseline.

Figure 4-15 illustrates the evaluators' cooling baseline characterization among ASHP systems. The figure distinguishes between early replacement baselines (preexisting operable equipment) and normal replacement/new construction baselines (code-compliant systems). Window air conditioners constituted nearly 60% of ASHP baselines. As mentioned earlier in this section, 12 systems across 9 sampled sites resulted in a cooling penalty, as customers indicated they would not have installed mechanical cooling systems if not for participating in the program.

Figure 4-15. Cooling baseline characterization of ASHP systems in Phase 2 sample




### 4.5.1.4 Additional ASHP Findings

Evaluators paired survey responses with metered results to examine other factors that could affect savings. Appendix J includes additional tables and figures supporting these findings.

- The **current usage of pre-existing heating systems** is a determinant of heat pump performance, as illustrated in Figure 4-9. Customers self-reporting to no longer use the pre-existing heat system had HPs that significantly outperformed those of customers who said they use legacy systems.
- MMBtu results vary when analyzed by **pre-existing heating fuel classification**, with electricity (MMBtu RR of 69%), oil (RR of 64%), and propane (RR of 57%) outperforming natural gas (RR of 31%). 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 (37% MMBtu RR) than single-head DMSHPs (34% MMBtu RR).
- **Tracked conditioned square footage** was a noticeable driver of ASHP MMBtu RR. ASHP installations associated with less than 1,500 square feet of tracked conditioned area performed significantly better (MMBtu RRs between 88% and 99%) than those associated with 1,500 to 4,000 square feet (RRs between 8% and 35%). This performance variation may be driven by contractor right-sizing or tracking data accuracy.
- **Controls for ducted ASHPs** can be more optimally programmed. While ducted ASHPs constituted only three of the 97 sampled ASHP projects, evaluators found that the controls for two 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. Twenty-three 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. Two 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 four customers in the Phase 2 sample self-reported having the heat pump controls integrated with another heating system. These four 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.

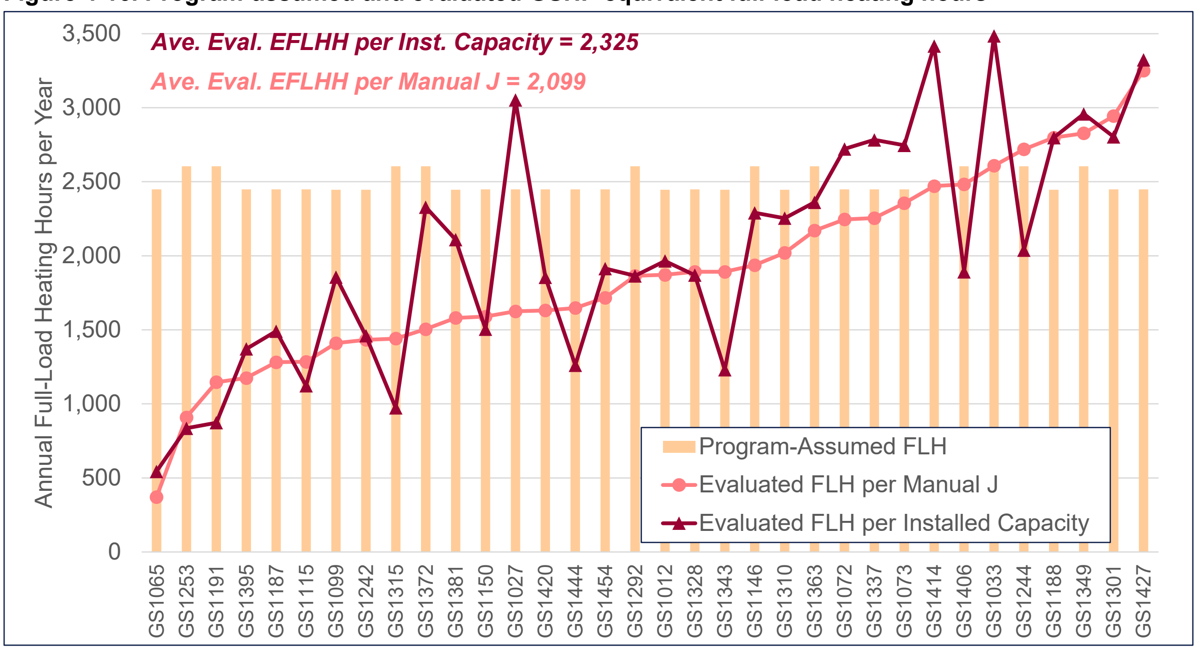
## 4.5.2 GSHP Parameters

This section examines GSHP M&V data in the context of different parameters affecting annual savings: heating and cooling output, full-load hours, efficiencies, and baselines.

### 4.5.2.1 Heating and Cooling Outputs

Evaluators determined, on average, that GSHPs operate for 84% of the equivalent full-load heating hours (EFLHH) per year assumed within the program's savings calculator. Figure 4-16 compares the program-assumed annual EFLHH values (vertical bars), evaluation metering EFLHHs as defined by installed capacity (dark red line), and evaluated EFLHHs as defined by Manual J heating load values estimated by participating contractors (light red line). Results are ordered from lowest evaluation $EFLHH_{ManualJ}$ to highest.

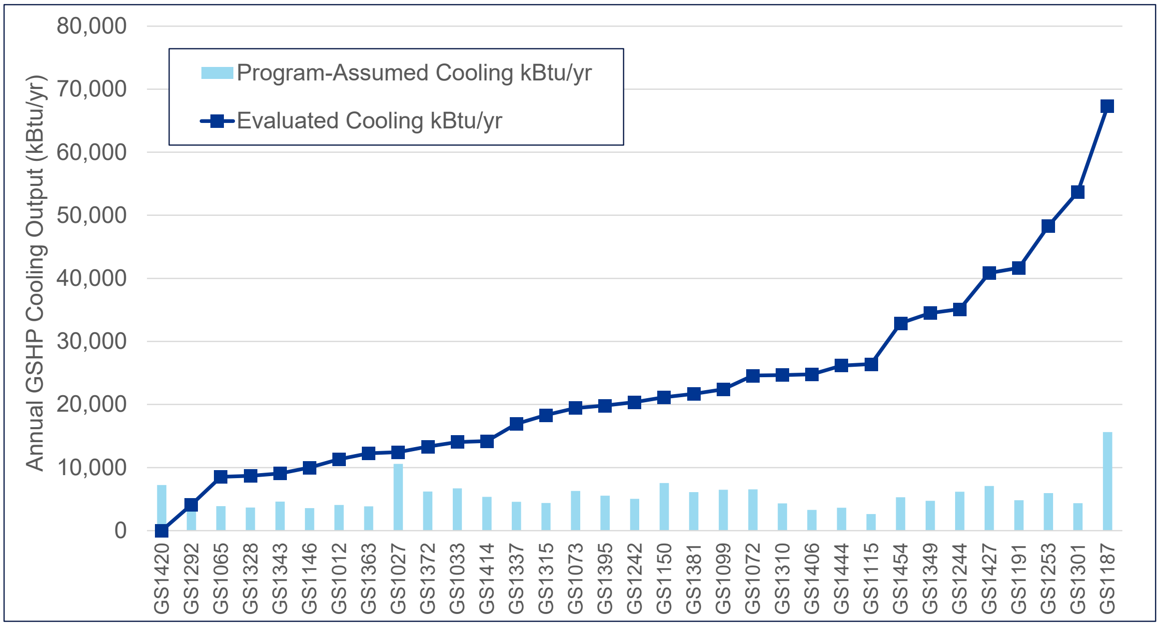
**Figure 4-16. Program-assumed and evaluated GSHP equivalent full-load heating hours**




The figure shows reasonable correlation between $EFLHH_{capacity}$ and $EFLHH_{ManualJ}$ for most GSHP projects in Figure 4-15, indicating that contractors are generally right-sizing the GSHP systems at or slightly above the building's Manual J heating load. The program's assumed EFLHH range from 2,230 (NYC) to 2,604 (Binghamton). Differences in heating operating hours reduced the GSHP MMBtu RR by 16%.

Evaluators determined a similarly wide range of GSHP cooling operation among sampled Phase 2 sites. Supporting information on the program's cooling savings claims was sparse, limiting the evaluators' ability to compare evaluated findings with program assumptions.[36] Figure 4-17 nonetheless presents evaluated annual cooling output (in increasing order) versus the evaluators' estimation of the cooling output embedded within program savings claims (vertical bars).

**Figure 4-17. Program-assumed and evaluated GSHP annual cooling output in kBtu/yr**




Annual cooling output for all GSHP sites in the evaluation sample exceeded that presumed in program savings claims, some by a factor of four or more. These significant differences in cooling operation only increased the GSHP MMBtu RR by 2%, as heating savings comprised a significant majority of overall evaluated MMBtu savings (see Figure 4-4). Evaluated cooling outputs, when compared with installed equipment capacities, corresponded to **363 equivalent full-load cooling hours (EFLCH) per year for GSHPs**. Comparatively, New York TRM Version 9 recommends a range of EFLCHs, from 246 (Binghamton) to 811 (New York City).

### 4.5.2.2 Performance

GSHP systems outperformed AHRI-rated efficiencies in both heating (in HSPF) and cooling modes (in SEER). Table 4-21 illustrates the weighted-average evaluated efficiency metrics as compared with AHRI ratings and program assumptions. Evaluators determined that GSHPs absorb heat from groundwater at a weighted average temperature of 45.0°F during the heating season; GSHPs reject heat to groundwater at a weighted average temperature of 62.7°F during the cooling season. These groundwater temperatures are slightly more favorable than the design conditions corresponding to rated conditions. Notably, the evaluated and program-assumed HSPFs were nearly identical.

[36] The evaluators reviewed the program's GSHP savings calculator and determined that program savings claims reflected an assumption that the cooling load equaled 24% of the Manual J heating load. However, information was unavailable on assumed cooling full-load hours per year. Evaluators referenced New York TRM Version 9 to estimate assumed annual cooling output as the product of the cooling load and annual full-load cooling hours by region.

Table 4-21. Evaluated vs. program-assumed efficiency metrics for GSHPs

| GSHP Efficiency Metric | Weighted Average Values | | |
|---|---|---|---|
| | Program-Assumed | Rated* | Evaluated |
| HSPF (Heating) | 13.77 | 12.25 | 13.81 |
| SEER (Cooling) | N.D.† | 18.46 | 19.99 |

* 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.

† Though the program claimed cooling savings for all GSHP installations, cooling COP was not evident in program tracking databases or savings calculators.

### 4.5.2.3 Baselines

In contrast with ASHPs, the program appeared to customize each GSHP project's savings to the site-specific heating fuel as reflected in tracked data. Evaluators determined that approximately half of sampled GSHP projects were early replacements of operable equipment, and achieved first-year savings reflected the efficiency gain as compared with preexisting systems. The program savings claims, on the other hand, more often reflected a code-compliant baseline as a result of normal replacement installations. This difference in baseline treatment led to an estimated 18% increase in the GSHP RR.

Figure 4-18 illustrates the evaluators' heating baseline characterization of 51 GSHP systems installed in 36 sampled projects.

Figure 4-18. Heating baseline characterization of GSHP systems in Phase 2 sample

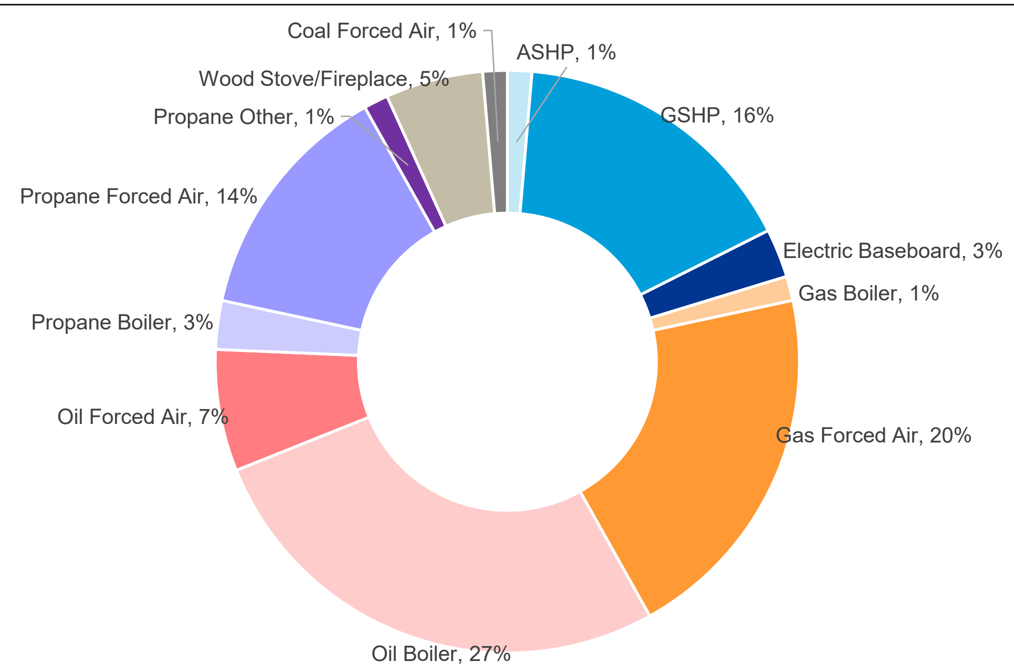
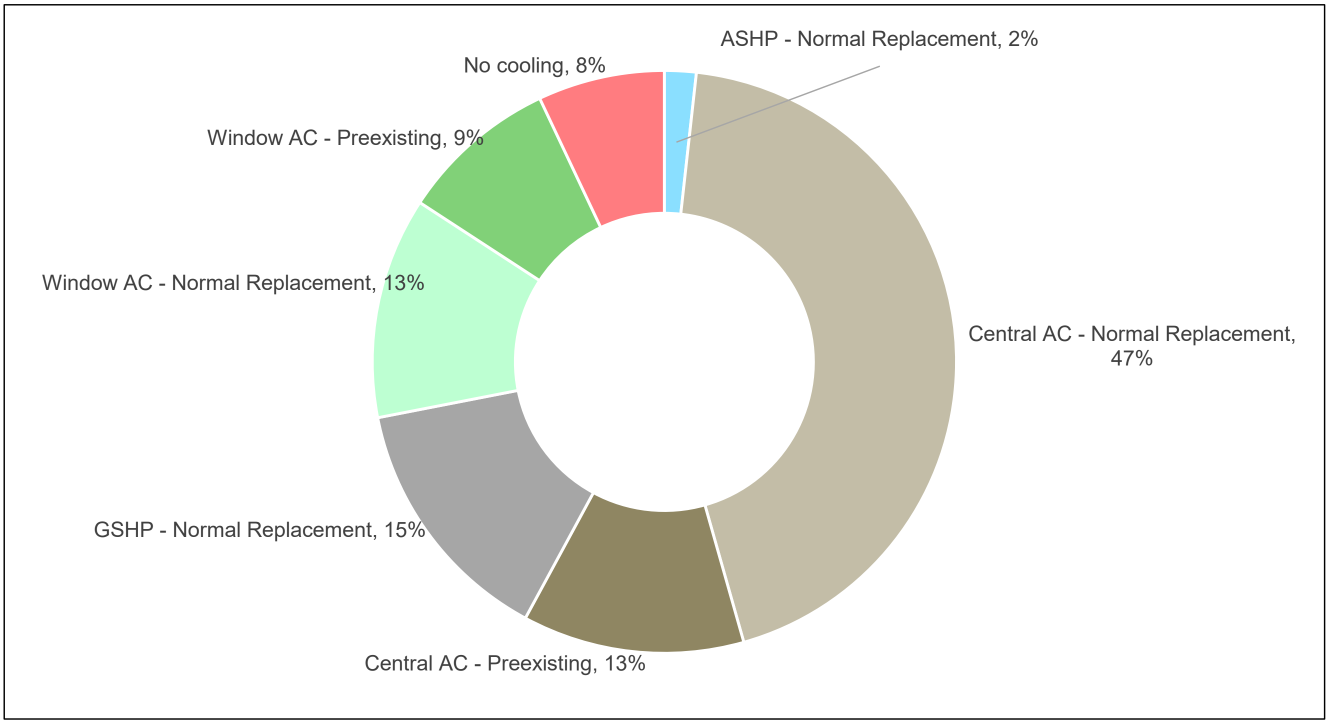



Figure 4-19 illustrates the evaluators' cooling baseline characterization among sampled GSHP systems. The figure distinguishes between early replacement baselines (preexisting operable equipment) and normal replacement/new construction baselines (code-compliant systems). 4 systems led to cooling penalties, as the customers indicated they would not have installed mechanical cooling systems if not for participating in the program.

**Figure 4-19. Cooling baseline characterization of GSHP systems in Phase 2 sample**




### 4.5.2.4 Additional GSHP Findings

The evaluation team paired the survey responses with metered results and observed additional drivers of GSHP impacts. Supporting tables and figures can be found in Appendix J.

- **Preexisting heating fuel** was a key driver of GSHP savings, with electric resistance (n=6, 401% MMBtu RR) and propane (n=6, 116%) outperforming oil (n=13, 63%), though low sample size is a consideration with the limited GSHP sample count.
- **Tracked conditioned square footage** is a key driver of GSHP savings, though differently than for ASHPs. Higher tracked conditioned square footage generally correlated with higher GSHP MMBtu savings. Most of the GSHP projects in the sample involved whole-home systems, though a small number of partial-home systems led to lower savings likely due to load-sharing with other heating systems.

# 5 CONCLUSIONS AND RECOMMENDATIONS

This report addresses the methods and results of a two-phase impact evaluation of three heat pump programs administered by NYSERDA through 2018. While the evaluated heat pump programs have been discontinued, the DNV evaluation team has framed the below conclusions and recommendations wherever possible to be applicable to the NY Statewide Clean Heat program currently administered by the state's joint electric utilities. This forward-looking context has been italicized to distinguish from recommendations specific to the evaluated NYSERDA programs.

***Program Accomplishments***

- **The evaluated programs led to energy savings and carbon emissions reductions.** The Underutilized Products, Heat Pumps and Solar Thermal, and Heat Pump Pilot Projects Demonstration programs led to significant MMBtu savings and offsets of fossil fuels, including 82,516 MMBtu of natural gas, 175,710 gallons of heating oil, and 283,870 gallons of propane. Overall, the realized energy savings offset approximately 7,801 tons of $CO_2$ from fossil fuels.
- **The programs accurately predicted MMBtu impacts from GSHPs.** Evaluated (Phase 2) MMBtu savings for GSHPs correlated with program-reported savings claims within 3%. The programs' customized savings claims, which were based on contractor building heating load estimates and site-specific information on preexisting heating fuel, were generally accurate.
- **The rebated heat pumps performed near rated efficiencies.** Overall, ASHPs performed closely to rated efficiencies, achieving a weighted average heating seasonal performance factor (HSPF) of 11.34. 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. Evaluated GSHP heating performance exceeded manufacturer ratings by 13% due to higher measured groundwater temperatures than assumed in design conditions. During the cooling season, ASHPs and GSHPs operated within 6% and 8% of rated SEER and EER, respectively.
- **Installed heat pumps led to cooling savings when compared with baseline systems.** Approximately half of 137 customers sampled for M&V did not have cooling systems before the heat pump installation. But 90% of those customers indicated they would have installed a mechanical cooling system if they had not participated in the program. Evaluated cooling savings increased the ASHP and GSHP RRs by 4% and 2%, respectively.
- **The programs engaged contractors to act as 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.
- **The rebated heat pumps function properly.** 89% of surveyed customers did not report any operational or maintenance issues with heat pumps. The remaining 11% reported various issues ranging from outdoor unit vibrations to misunderstanding the system control panel.

***Key Evaluation Findings***

- **Billing analysis results underestimated the M&V results for ASHPs.** The ASHP MMBtu savings RR from 97 M&V deployments (evaluation Phase 2) was 11% higher than the RR determined from premise-level consumption data analysis of 128 ASHP projects (evaluation Phase 1). The difference is primarily attributable to the Phase 2 baseline treatment that more frequently defaulted to fossil fuel alternatives. Aligning the baseline treatment between the two phases would have reduced the Phase 2 MMBtu RR to 32%, indicating reasonable prediction from premise-level analysis.
- **Phase 2 evaluated savings significantly exceeded Phase 1 savings for GSHPs.** On the other hand, for GSHPs, M&V results demonstrated 44% higher MMBtu savings as compared with premise-level consumption analysis.

Evaluators primarily attribute this difference to revised site-specific baselines in Phase 2 that incorporated customer preferences for alternative heating and cooling systems absent program influence.

- **Evaluated savings correlate with pre-existing system type and use.** Phase 1 and Phase 2 results demonstrated that savings are most realized when heat pumps are used as the primary heating equipment. Customers that no longer use pre-existing heating equipment achieved a 40% higher RR than customers continuing to use legacy systems.
- **Evaluated savings correlate with climate zone.** ASHP projects performed significantly better in upstate climate zones 5 and 6 as compared with downstate climate zone 4. Evaluators found that downstate ASHPs operated for fewer heating hours than upstate systems for two primary reasons: 1) higher likelihood of downstate customers using pre-existing heating systems, and 2) smaller conditioned square footage per installed ton. Heating degree days for **d**ownstate customers are lower than for upstate customers, but weather was not as significant a factor as partial displacement frequency, customer usage patterns, and unit oversizing. GSHP projects in climate zone 5 achieved higher MMBtu savings than those in climate zone 6 by 43%.
- **Customers are adding cooling comfort to their lifestyle.** The Phase 1 web survey observed that 25% of spaces with a program heat pump installed were adding cooling to previously uncooled space.[37] 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 approximately 6 degrees. This change in temperature is a significant addition of cooling comfort that could reduce energy savings at the meter. Evaluation analysis models presume that setpoint adjustments would have been made to the baseline alternative system as well.

***Opportunities to Improve Savings Estimates***

- **Evaluated ASHP savings fell short of program-reported estimates.** Program-rebated ASHP installations led to 62% lower evaluated MMBtu savings compared to program-reported values. The key contributors to the 38% RR for ASHPs are summarized in bullets below.
- **Installed heat pumps provide less heating than assumed by the programs.** The primary driver of the ASHP RR is 56% lower annual heating output than assumed within program savings claims. Phase 2 metered data, extrapolated over a full year and correlated with installed equipment capacities, led to 565 average annual full-load heating hours across the ASHP population of projects, of which over 99% involved DMSHPs. While the body of heat pump evaluation research is rapidly growing, other DMSHP studies in the Northeast have shown similar findings of approximately 450 annual full-load heating hours.[38] In the context of the current New York TRM 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. For GSHPs, evaluators determined weighted average FLHs of 2,325 (per installed capacity) or 2,099 (per tracked Manual J building heating load), whereas the program's savings calculator featured FLHs ranging from 2,230 to 2,604.
- **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.
- **A single deemed savings value is not appropriate for heat pump installations.** With ASHPs encompassing 90% of the evaluation population, their results had significant impacts on the program-level VGS realization rates. The

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[37] The Phase 2 M&V sample showed a higher share of such customers with at least one *system* that cooled a previously uncooled space.

[38] Massachusetts and Rhode Island Electric and Gas Program Administrators. 2016. "Ductless Mini-Split Heat Pump Impact Evaluation." http://www.ripuc.ri.gov/eventsactions/docket/4755-TRM-DMSHP%20Evaluation%20Report%2012-30-2016.pdf

programs assumed a single deemed savings value per outdoor unit for all ASHP installations, not accounting for unit size, baseline, displacement share, or climate. The programs' ASHP 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. 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 single deemed value contributes to significant variability in evaluation results.

  - **Recommendation:** Reflecting the above four conclusions, ASHP savings claims should be based on site-specific baseline fuel, system type if electric, unit size, location, and expected load displacement relative to size. This study's DMSHP results suggest a default displacement factor of 0.3 relative to total building heating load. The current version of the New York TRM[39] provides detailed guidance on estimating heating and cooling loads for partial- and full-displacement installations. Use of either a quasi-prescriptive calculator, or deemed savings options based on displacement fraction, would markedly improve savings estimates. Crucial to the success of this recommendation is contractor training and oversight to ensure that installed systems are right-sized and credibly characterized based on the portions of heating and cooling loads to be satisfied by the heat pumps. *Based on the evaluators' review of its program manual, the Clean Heat Program requires administering utilities to abide by the current New York TRM. When an installation is not covered by a prescribed measure in the TRM, the program requires a custom track.* [40]

- **Quantifying evaluated impacts by fuel proved difficult.** For all ASHP installations, the programs claimed all fossil fuel savings as oil, limiting the evaluators' ability to expand evaluation results from the sample to the population of projects. Among 86 ASHP projects in the evaluation sample, we found that program-rebated installations led to a diversity of savings by fuel, including natural gas (comprising 29% of total MMBtu savings across all fuels), fuel oils (36%), propane (18%), and wood (5%). For GSHP installations, the program claimed a broader diversity of fuel-specific savings, though evaluators determined higher shares of natural gas and propane, and lower shares of fuel oils, than claimed.
  - **Recommendation:** Heat pump savings claims should distinguish among different displaced heating fuels as documented by the installation contractor. Fuel-specific impacts are critical for measuring program success versus statewide carbon emissions reduction goals. A single installation might displace more than one heating fuel; therefore, approved contractors should be trained to collect defensible information on pre-existing heating fuel types and shares. When feasible, utility-led programs should leverage historical natural gas consumption data at the participant address to corroborate the tracked estimates for pre-existing natural gas systems.
- **A minority of participating customers would have installed heat pumps regardless of the program.** For 15% of rebated ASHPs, customers indicated via in-person interviews that they would have installed heat pumps regardless of program intervention. Heat pump baselines reduce the achievable savings significantly, as heat pumps can satisfy heating loads much more efficiently than fossil fuel- or resistance-based systems. Due to complexities with establishing the influence of the programs on accelerating the heat pump market in New York, evaluators calculated gross impacts for such ASHP projects by considering the most reasonable, code-compliant fossil fuel-fired system as baseline. Evaluators acknowledge that these predecessor heat pump programs likely included early adopter participants whose decision-making might not be representative of future heat pump program participants.

[39] New York State Joint Utilities, "New York TRM Version 9," effective January 2022. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf

[40] New York State Joint Utilities, "NYS Clean Heat Statewide Heat Pump Program Manual Version 5," October 2021. https://saveenergy.ny.gov/NYScleanheat/assets/pdf/NYS-Clean-Heat-Program-Manual.pdf

- **Recommendation:** For heat pump installations in new construction or end-of-life scenarios, savings should be informed by the customers' preferred alternative systems and fuel choices in the absence of the program. While accounting for program influence will continue to be a challenge, evaluators recommend that future heat pump installations comport with the guidance in the active New York TRM.[41] Eligible Program tracking databases should intake relevant site-specific variables and triangulate the most appropriate baseline against which new construction or end-of-life performance is measured.

- **Evaluators observed a small share of GSHP-to-GSHP installations.** During the evaluation planning process, evaluators identified that an additional 20 GSHP installations in the population involved replacement of existing GSHP systems. These projects were removed from the evaluation sampling frame. The New York TRM currently does not accommodate a GSHP baseline.[42]
    - **Recommendation**: GSHP-to-GSHP replacements should be considered as a prescribed scenario by the New York TRM Committee, as the team expects this to become more common as first generation GSHPs begin to reach their effective useful life. *The Clean Heat Program does not appear to accommodate such a baseline, though new construction GSHP projects are required to be submitted through a custom track.*
- **Many participants continued to use pre-existing HVAC systems.** The Phase 1 web survey found that approximately 75% of program participants continued to use pre-existing heating and cooling systems after heat pump installation. These partial displacement scenarios reduce the achieved savings as demonstrated by lower-than-expected outputs and full-load hours as described above.
    - **Recommendation:** Program administrators should consider a tiered incentive approach that rewards full-displacement installations. Training and requiring approved contractors to credibly collect and track this information is crucial to the success of this recommendation.
    - **Recommendation:** Programs should similarly reward partial-displacement installations that include integrated controls that manage heat pump use with legacy systems. There may be limitations to the ability of controls on older pre-existing systems that will need to be acknowledged in such an effort. *Based on the evaluators' review of its program manual, the Clean Heat Program has established nine installation categories with varying incentive structures and eligibility criteria that distinguish among system types, partial- and full-displacement installations, and inclusion of integrated controls.*[43]
    - **Recommendation**: Programs should educate eligible contractors and participating customers on the best practices for optimal heat pump usage, particularly for installations that supplement existing heating systems. Heat pump adoption and savings potential rely heavily on customer awareness of heat pump benefits and their ability to satisfy heat loads during extreme winter temperatures. *The Clean Heat Program manual recommends continuous contractor training, and its website includes a list of educational resources for participating contractors.*[44] *It is unclear if or how the program administrators ensure that contractors review such resources.*

***COVID Implications***

- **COVID has led to higher energy usage per customer.** Total customer-level, weather-normalized energy usage increased by 6.5 MMBtu or 8% between the COVID period (post-March 2020) and pre-COVID periods (pre-March

[41] NY TRM Version 9, active at the time of this writing and referenced below, states that "The baselines used in [the ASHP] measure are determined by the type of equipment that would have been installed without the influence of the program supporting the installation of this measure."

[42] New York State Joint Utilities, "New York TRM Version 9," effective January 2022. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf

[43] New York State Joint Utilities, "NYS Clean Heat Statewide Heat Pump Program Manual Version 5," October 2021. https://saveenergy.ny.gov/NYScleanheat/assets/pdf/NYS-Clean-Heat-Program-Manual.pdf

[44] https://saveenergy.ny.gov/NYScleanheat/resources/

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 represented less than 1% of the total energy usage, monthly billing analysis may not be sensitive enough to detect these smaller changes in cooling load.

Relatedly, 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 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.

- **Most customers have not adjusted their comfort preferences during COVID.** 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 setpoint saw a direct correlation in an increase in their heating load (3.6 MMBtu or 14% increase in heating load).